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SOME OBSERVATIONS ON STELLAR MOTIONS IN THE LINE OF SIGHT MADE AT THE EMERSON McMILLIN OBSERVATORY.

By H. C. Lord.

In a paper read before the conference of astronomers held at the opening of the Yerkes Observatory, an abstract of which was published in this Journal, **6**, 5, I gave an account of the work undertaken at the Emerson McMillin Observatory upon stellar motions in the line of sight. The observations there published seemed to indicate that the instrument was in satisfactory adjustment and that the accuracy reached was about all that could be expected from the instrumental power at my command. I also called attention to the fact that there were some twenty to twenty-five stars of type II*a* given in the Draper Catalogue, whose velocities had, so far as I know, not been determined, and which were nevertheless bright enough to be observed with the instruments here. Upon my return from Williams Bay, systematic work was begun upon these stars. As this work will require some time for its completion it has seemed to me advisable, as the work upon the separate stars shall be completed, to publish the results in advance of a general discussion. These results are not definitive, but any subsequent changes will not materially alter the values given.

The instrument used has already been described. One important change should be noted; upon the frame of the spectroscope, as far removed from the prisms as possible and at points where the heat of the prisms would be lost through conduction to the heavy metal parts of the telescope, are placed coils of wire, connected through a switch to four cells of storage battery. These coils are of such resistance as to allow a current of from five to seven amperes to flow through them. The whole spectroscope is also inclosed in a tight fitting covering of two thicknesses of felt and one of black velvet. A thermometer is placed in the prism box, the bulb not touching the metal and the stem projecting through the felt and velvet cover. This thermometer is read from time to time during the exposure, and as soon as the mercury starts to fall the current is turned on the coils for from 60 to 120 seconds. After a few minutes the mercury will rise to its normal point. The temperature lag is very great, but a little practice enables the observer to allow for it, and the temperature of the thermometer can easily be kept within ½° F. while the temperature on the outside falls from five to ten degrees. Though this may not represent the temperature of the prisms exactly, yet since the thermometer is placed in the air surrounding them, I feel confident that they must be kept at a fairly constant temperature.

The hydrogen tube is placed on an arm which can be swung over and about eight inches in front of the slit, directly in the cone of rays.

The method of taking the photographs is as follows. The telescope is set on the star, the hydrogen tube placed in position and exposure on the tube of from ten to twenty seconds is given. The tube is then removed and the exposure on the star given, after which the tube is replaced and a second exposure of the same length as the first given on the artificial line.

The method of measuring the plates is substantially that given in the Potsdam Publications, Vol. 7, for the type II*a* stars, except that in every case the plates were measured in two positions under the microscope, once with the red end on the right and the solar standard below the star spectrum, and once

with the red end on the left and the solar spectrum above the star spectrum. The solar standard No. 454 was used in all these observations. This spectrum is about four times as wide as the star spectra but much narrower than the solar standard used in the earlier observations above quoted.[1]

On this plate 1^{mm} corresponds to a velocity 1443^{km} per second. The velocity is also computed for each line compared. The separate results together with the collected means are given below. Plate No. 438 has been rejected from the means. This plate was so badly underexposed that I rejected it twice before measuring but at last was induced to try it. I find in the record of the observations that at the end of the exposure the objective was badly dewed and hence have decided to reject this value at least for the present. On account of the large difference between Red End Right and Red End Left in Plate 488 it was remeasured. The small value -5.2 might have been due to recording the setting on the artificial $H\gamma$ for that on the star $H\gamma$ and *vice versa*. The mean of the two values is adopted.

As a further check on the work, the observations on ι Aurigae and ϵ Geminorum were reduced, regarding the solar parallax and the star's velocity with respect to the Sun as unknown. The values found are for ι Aurigae: $V_s+21.4$, $\pi=9''.2$ and for ϵ Geminorum: $V_s+12.0$, $\pi=10''.1$. This agreement of these values of V_s thus found with those previously obtained and that of π with the true value would seem entirely satisfactory.

It is as yet too soon to discuss the probable error of these observations, but from the thirty-six residuals (rejecting plate 438) I find that the probable error of a single observation is about 2^{km} per second, which corresponds to a displacement on the photographic plate of only $0^{mm}.0018$.

The faintest star yet photographed is ι Aurigae, with a photographic magnitude of 4.87. The Draper Catalogue gives

[1] In the abstract above quoted 1^{mm} displacement on the plate is said to correspond to a velocity of $143^{km}.7$ per second. This is an error. It should have been 1437^{km} per second.

OBSERVATIONS FOR MOTION IN THE LINE OF SIGHT.

Plate number	Star	Date	Exposure time	Observed velocity			Reduction to the Sun	Velocity reduced to the Sun
				Red end right	Red end left	Mean		
441	ι Aurigae	Nov. 20, 1897	75^m	+12.7	+ 5.2	+ 8.9	+ 7.9	+16.8
443	"	" 23, "	80	+21.2	+16.2	+18.7	+ 6.9	+25.6
461	"	Jan. 8, 1898	80	+40.0	+41.4	+40.7	−16.1	+24.6
465	"	" 23, "	75	+47.9	+45.8	+46.9	−21.9	+25.0
467	"	" 24, "	70	+44.3	+40.7	+42.5	−22.4	+20.1
468	"	" 27, "	75	+40.1	+38.4	+39.2	−23.5	+15.7
471	"	Feb. 1, "	75	+51.1	+45.8	+48.4	−25.0	+23.4
473	"	" 3, "	75	+43.3	+39.0	+41.2	−25.6	+15.6
475	"	" 6, "	75	+52.2	+47.2	+49.7	−26.3	+23.4
480	"	" 25, "	80	+48.9	+46.0	+47.4	−29.2	+18.2
							Mean	+20.8
438*	ε Geminorum	Nov. 17, 1897	80	+11.9	+11.6	+11.7	+19.9	[+30.7]
438*	"	" 17, "	80	+ 8.9	+10.9	+ 9.9		
442	"	" 20, "	75	− 4.2	− 9.5	− 6.9	+18.8	+11.9
444	"	" 23, "	90	− 2.3	− 9.7	− 5.9	+17.7	+11.8
462	"	Jan. 8, 1898	90	+16.7	+11.8	+15.2	− 5.2	+10.0
469	"	" 27, "	75	+32.2	+25.9	+29.0	−15.0	+14.0
472	"	Feb. 1, "	75	+31.7	+28.0	+29.9	−17.0	+12.9
474	"	" 3, "	75	+28.7	+25.6	+27.1	−17.9	+ 9.2
476	"	" 6, "	75	+37.0	+34.1	+35.5	−19.0	+16.5
485	"	Mar. 13, "	70	+45.9	+41.7	+43.8	−28.7	+15.1
489	"	" 14, "	75	+46.2	+44.0	+45.1	−28.8	+16.3
							Mean	+13.1
486	ε Leonis	Mar. 13, 1898	50	+29.2	+24.4	+26.8	−16.0	+10.8
490	"	" 14, "	45	+24.1	+23.4	+23.8	−16.4	+ 7.4
496	"	" 25, "	45	+28.1	+26.1	+27.1	−20.6	+ 6.5
500	"	" 31, "	45	+34.3	+25.8	+30.1	−22.7	+ 7.4
504	"	April 7, "	45	+34.7	+28.5	+31.6	−24.8	+ 6.8
							Mean	+ 7.8
487	ψ Urs. maj.	Mar. 13, 1898	70	+18.3	+ 9.9	+14.1	−10.3	+ 3.8
491	" "	" 14, "	70	+16.2	+ 9.0	+12.6	−10.7	+ 1.9
494	" "	" 24, "	70	+10.8	+10.2	+10.5	−14.2	− 3.7
497	" "	" 25, "	70	+ 8.6	+ 6.5	+ 7.6	−14.5	− 6.9
501	" "	" 31, "	70	+15.6	+11.5	+13.6	−16.4	− 2.8
505	" "	April 7, "	70	+25.9	+20.7	+23.3	−18.4	+ 4.9
							Mean	− 0.4
488§	ε Virginis	Mar. 13, 1898	75	− 5.2	−16.1	−10.7	+ 7.9	− 5.1
488§	"	" 13, "	75	−11.6	−18.9	−15.3		
492	"	" 14, "	75	−15.8	−15.8	−15.8	+ 7.4	− 8.4
495	"	" 24, "	75	−13.5	−14.3	−13.9	+ 2.5	−11.4
498	"	" 25, "	50	− 8.5	− 9.6	− 9.0	+ 2.2	− 6.8
502	"	" 31, "	75	− 9.4	−13.8	−11.6	− 0.8	−12.4
506	"	April 7, "	75	− 4.8	− 6.9	− 5.8	− 4.5	−10.3
							Mean	− 9.1

* Plate 438 was rejected on account of underexposure.

§ Plate 488 was measured twice.

Velocities are given in kilometers per second. The + sign denotes recession; the − sign approach.

twenty-four stars north of the Equator classed as *K*, brighter than 4.89, whose velocities have not been determined at Potsdam, and eleven stars of types *M* and *Q*. These stars will be investigated as rapidly as possible, at least five satisfactory photographs of each star being secured.

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ON THE SERIES SPECTRA OF OXYGEN, SULPHUR, AND SELENIUM.

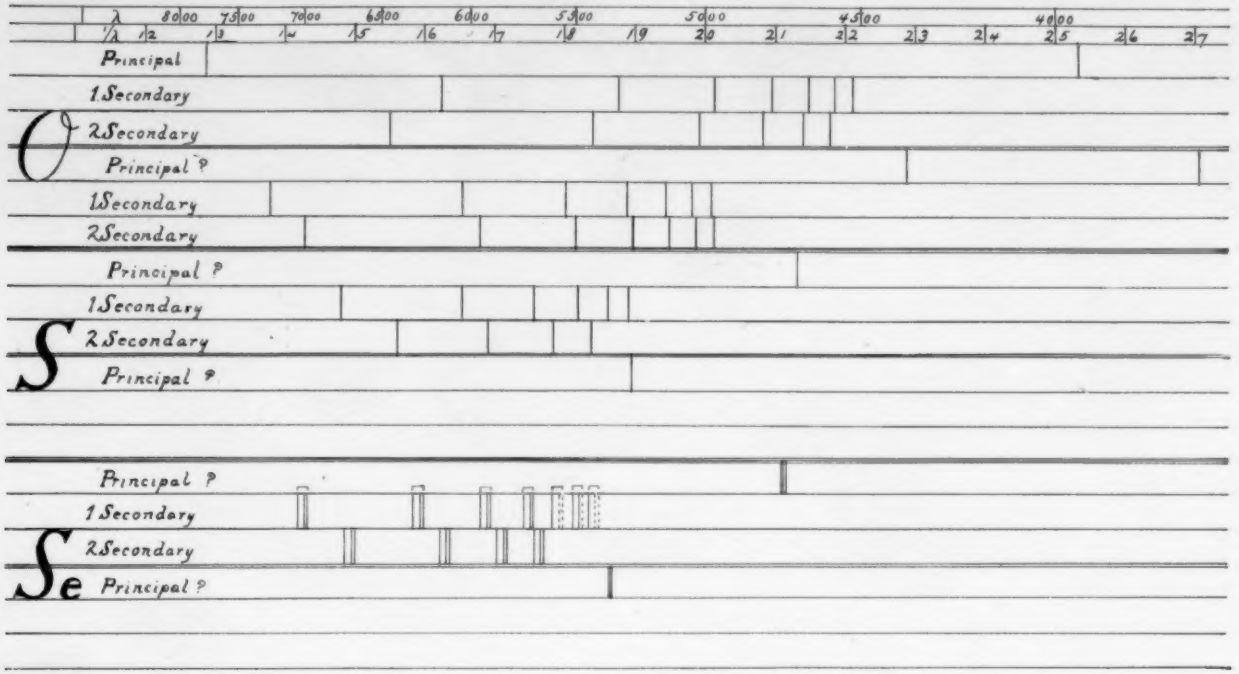
By C. RUNGE and F. PASCHEN.

I. OXYGEN.

WE may say that there are six different spectra of oxygen. First, there are two absorption spectra, as Janssen has shown. They differ in the variation of their intensity. One increases in intensity proportional to the density of the gas, the other proportional to the square of the density. Then there are four different emission spectra of oxygen in the vacuum tube, as Schuster has shown. A continuous spectrum, a band spectrum near the cathode, the spark spectrum, and the "compound line spectrum." We propose to alter the name of the compound line spectrum, and to call it series spectrum, because we have found that the lines are distributed in "series" similar to those that had been found in the spectra of many other elements. This is the spectrum with which the present investigation deals. At the same time we have found that sulphur and selenium, under similar conditions, also emit series spectra, which seem to be analogous to the series spectrum of oxygen. For producing the spectra we used the arrangement devised by Paalzow and H. W. Vogel.[1] Both sides of the vacuum tube are separately connected with the pump. Both connections pass through U tubes, one containing sulphuric acid and electrodes to generate oxygen, the other containing a solution of potassium bichromate in concentrated sulphuric acid to keep off the impurities of the grease of the stopcocks. The same arrangement was used for the investigation of sulphur and selenium, with the sole addition of a wider part at one end of the tube, which contained H_2SO_4 or H_2SeO_4 (see Fig. 1). The electrodes were made of platinum foil.

[1] PAALZOW and H. W. VOGEL, *Wied. Ann.*, **13**, 336, 1887.

PLATE II.



SERIES SPECTRA OF OXYGEN, SULPHUR AND SELENIUM.

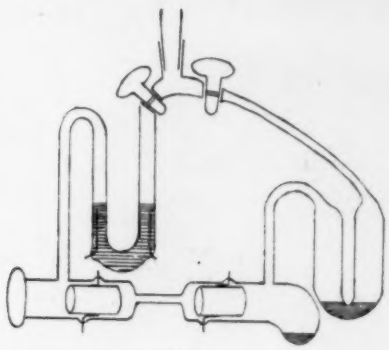


FIG. 1.

OXYGEN.

Wave-length	Mean error	Number of determinations	Intensity	Remarks
2883.95	0.01	4	6	
3692.586	0.003	3	7	
3823.714	0.018	2	7	
3825.22	0.04	3	6	
3830.41	0.07	3	2	
3947.480	0.010	3	10	The differences between the wave-lengths of this triplet are more accurate than the absolute wave-lengths.
3947.661			7	
3947.759			4	
3954.775	0.020	3	8	
4217.25	0.04	4	4	
4222.94	0.01	8	5	
4233.48	0.03	9	7	
4368.466	0.010	3	10	
4522.95				Double.
4523.70				
4576.97	0.11	2	2	Double.
4577.84	0.06	2	3	
4589.16	0.06	2	2	Double.
4590.07	0.06	2	3	
4654.41		1	2	
4654.74		1	3	
4655.54	0.03	4	4	
4672.93	0.06	3	3	Double.
4673.88	0.04	4	3	
4772.72	0.02	2	3	
4773.07	0.05	2	4	
4773.94	0.01	6	5	
4801.98	0.14	2	2	
4802.38	0.10	2	3	
4803.18	0.03	8	4	
4967.58	0.04	3	4	

OXYGEN — *continued.*

Wave-length	Mean error	Number of determinations	Intensity	Remarks
4968.04	0.04	3	5	
4968.94	0.01	3	6	
4973.05		1	1	Diffuse.
4979.73		1	1	Diffuse.
5018.96	0.04	2	3	
5019.52	0.07	2	4	
5020.31	0.01	13	5	
5037.34	0.5	3	2	Diffuse.
5047.88	0.1	4	2	Diffuse.
5130.70	0.07	9	3	
5146.23	0.03	3	5	
5275.25	0.04	7	4	
5299.17	0.03	3	5	
5329.162	0.01	3	6	
5329.774			7	
5330.835			10	
5405.08	0.10	6	3	
5408.80	0.04	7	4	
5410.97	0.03	7	3	
5435.371	0.015	3	5	
5435.968			6	
5437.041			8	
5512.92	0.02	3	5	Double, weak component on the more refrangible side.
5555.16	0.04	3	6	Double, weak component on the more refrangible side.
5750.82	0.04	2	5	
5958.75	0.02	6	6	Double, weak component on the more refrangible side.
5992.67		1	3	
5995.70	0.15	3	4	
6046.336	0.03	6	2	
6046.564			7	There is a weak line at 6107 (intensity 2) that we did not measure.
6156.198	0.018	7	7	
6156.993			8	
6158.415			10	
6256.81	0.05	1	1	
6261.68	0.03	1	3	
6264.78	0.09	1	1	
6267.06	0.04	1	1	
6453.900	0.015	5	6	
6454.756			7	
6456.287			9	
7002.48	0.13	4	4	There are weak lines at 7157, intensity 1, and 7474, intensity 1, that we did not measure.
7254.32	0.13	1	2	
7772.26	0.07	5	10	
7774.30	0.15	3	8	The mean error 0.15 refers to the mean of the two wave-lengths. Their distance is less accurate, as the lines were not easily seen separated.
7775.97			6	

The triplet in the extreme red part near 7770 is probably the strongest of the whole spectrum, considering how little sensitive the eye is for these rays. A singular interest is attached to it, as the three components coincide with three solar lines of equal relative intensities.[1] Jewell has observed them with high and low Sun. After first suspecting them to be water-vapor lines of terrestrial origin, he later on came to the conclusion that they are probably true solar lines.[2]

There are thirteen triplets of similar appearance, whose wave-numbers show the same differences. They decrease in intensity with decreasing wave-length, and form two "secondary series," as will be shown later on. The wave-numbers given in the following table are the reciprocals of the wave-lengths reduced to vacuum, and the decimal is placed so that we have the number of waves per centimeter in vacuo.

TRIPLETS.

Wave-length	Wave-number	Difference	Wave-length	Wave-number	Difference
6456.287	15484.57		4803.18	20813.84	
		368			346
6454.756	15488.25		4802.38	20817.30	
		205			174
6453.900	15490.30		4801.98	20819.04	
6158.415	16233.52		4773.94	20941.31	
		376			381
6156.993	16237.28		4773.07	20945.12	
		210			154
6156.198	16239.38		4772.72	20946.66	
5437.041	18387.34		4673.88	21389.62	
		363			435
5435.968	18390.97		4672.93d	21393.97	
		202			
5435.371	18392.99		4655.54	21473.88	
					369
5330.835	18753.65		4654.74	21477.57	
		374			152
5329.774	18757.39		4654.41	21479.09	
		215			
5329.162	18759.54		4590.07	21780.17	
					432
5020.31	19913.63		4589.16d	21784.49	
		315			
5019.52	19916.78		4577.84	21838.35	
		221			415
5018.96	19918.99		4576.97d	21842.50	
4968.94	20119.50				
		364	4523.70	22099.71	
4968.04	20123.14				366
		187	4522.95d	22103.37	
4967.58	20125.01				

[1] RUNGE and PASCHEN, "Oxygen in the Sun," this JOURNAL, **4**, December 1896.

[2] JEWELL, this JOURNAL, **5**, February 1897 and **6**, November 1897.

In the four weakest triplets the two weaker components could not be measured separately. In the four strongest triplets the distances of the components could be determined with our large concave grating of $6^m.5$ radius. They are therefore far more accurate than the differences in the other triplets. They give as the mean of the differences

3.70 and 2.08.

In the following table we give the wave-numbers of each triplet corrected to these values. The components are altered according to their weights in such a manner that the center of gravity remains unaltered. The weights of the three components were assumed equal to 3, 2, 1, which very nearly corresponds to the accuracy of their determination.

WAVE-NUMBERS.

Wave-number	Corrected wave-number	Difference	Corresponding deviation of wave-length
15484.57	15484.56	— 0.01	0.004
15488.25	15488.26	+ 0.01	— 0.004
15490.30	15490.34	+ 0.04	— 0.017
16233.52	16233.55	+ 0.03	— 0.011
16237.28	16237.25	— 0.03	+ 0.011
16239.38	16239.33	— 0.05	+ 0.019
18387.34	18387.30	— 0.04	+ 0.012
18390.97	18391.00	+ 0.03	— 0.009
18392.99	18393.08	+ 0.09	— 0.027
18753.65	18753.68	+ 0.03	— 0.009
18757.39	18757.38	— 0.01	+ 0.003
18759.54	18759.46	— 0.08	+ 0.023
19913.63	19913.38	— 0.25	+ 0.063
19916.78	19917.08	+ 0.30	— 0.076
19918.99	19919.16	+ 0.17	— 0.043
20119.50	20119.44	— 0.06	+ 0.015
20123.14	20123.14	0.00	0.000
20125.01	20125.22	+ 0.21	— 0.052
20813.84	20813.66	— 0.18	+ 0.042
20817.30	20817.36	+ 0.06	— 0.014
20819.04	20819.44	+ 0.40	— 0.093

WAVE-NUMBERS—(*continued.*)

Wave-number	Corrected wave-number	Difference	Corresponding deviation of wave-length
20941.31	20941.28	— 0.03	+ 0.007
20945.12	20944.98	— 0.14	+ 0.032
20946.66	20947.06	+ 0.40	— 0.091
21473.88	21473.78	— 0.10	+ 0.022
21477.57	21477.48	— 0.09	+ 0.020
21479.09	21479.56	+ 0.47	— 0.102

The corrections are throughout within the errors of observation. As to the four triplets where the two weaker components could not be measured separately, the difference between the wave-number of their mean and that of the strongest component ought to be 4.74. But as the two weaker components differ in intensity, the measurements do not give the mean, but a wave-length nearer to the stronger of the two. From photographs of the other triplets where the two weaker components are not separated, we concluded that the measurements ought to give 4.41 instead of 4.74. They actually give the differences 4.35, 4.32, 4.15, 3.66. The corresponding corrections of the wave-lengths would be 0.007, 0.008, 0.027, 0.078 Ångström units. Thus the corrected wave-numbers of the strongest component are:

21389.59
21780.13
21838.22
22099.33

The distribution of the thirteen triplets over the spectrum is most regular, as may be seen from Plate II. They form two series ending at the same place, similar to the two series of triplets in the spectra of magnesium, calcium, strontium and of zinc, cadmium, mercury.[1]

The wave-numbers may be represented with considerable accuracy by the formulæ

[1] KAYSER and RUNGE, *Abhdl. d. K. Akad. d. W., Berlin*, 1891. RYDBERG, *Svenska vetensk. Akad. Handl.*, **23**, No. 11.

$$A - \frac{B}{n^2} - \frac{C}{n^3} \text{ or } A - \frac{B}{n^2} - \frac{C}{n^4},$$

where A, B, C are constants and n stands for the values 3, 4, 5. . . . . The first formula is more accurate than the second. In both series the triplets decrease in intensity with increasing wave-number. But one of the series as a whole is decidedly stronger than the other.

STRONGER SERIES.

Strongest component, - -	23207.93	$-110387.7n^{-2}$	$-4814n^{-3}$
Middle component, -	23211.63	$-110387.7n^{-2}$	$-4814n^{-3}$
Weakest component, - -	23213.71	$-110387.7n^{-2}$	$-4814n^{-3}$

n	Wave-number calculated	Wave-number observed	Obs.–calc.	Correspondence difference of wave length
4	16233.48	16233.52	+ 0.04	— 0.02
	16237.18	16237.28	+ 0.10	— 0.04
	16239.26	16239.38	+ 0.12	— 0.04
5	18753.91	18753.65	— 0.26	+ 0.07
	18757.61	18757.39	— 0.22	+ 0.06
	18759.69	18759.54	— 0.15	+ 0.04
6	20119.32	20119.50	+ 0.18	— 0.04
	20123.02	20123.14	+ 0.12	— 0.03
	20125.10	20125 01	— 0.09	+ 0.02
7	20941.08	20941.31	+ 0.23	— 0.05
	20944.78	20945.12	+ 0.34	— 0.08
	20946.86	20946.66	— 0.20	+ 0.05
8	21473.72	21473.88	+ 0.16	— 0.03
	21477.42	21477.57	+ 0.15	— 0.03
	21479.50	21479.09	— 0.41	+ 0.09
9	21838.52	21838.35	— 0.17	+ 0.04
	21842.22	21842.50d		
	21844.30			
10	22099.24	22099.71	+ 0.47	— 0.10
	22102.94	22103.37d		
	22105.02			

WEAKER SERIES.

Strongest component,	- 23193.85	$-107567.1\,n^{-2}$	$-63108\,n^{-3}$
Middle component,	- 23197.55	$-107567.1\,n^{-2}$	$-63108\,n^{-3}$
Weakest component,	- 23199.63	$-107567.1\,n^{-2}$	$-63108\,n^{-3}$

n	Wave-number calculated	Wave-number observed	Obs.–calc.	Corresponding difference of wave-length
4	15484.84	15484.57	— 0.27	+ 0.11
	15488.54	15488.25	— 0.29	+ 0.12
	15490.62	15490.30	— 0.32	+ 0.13
5	18386.30	18387.34	+ 1.04	— 0.31
	18390.00	18390.97	+ 0.97	— 0.29
	18392.08	18392.99	+ 0.92	— 0.27
6	19913.71	19913.63	— 0.08	+ 0.02
	19917.41	19916.78	— 0.63	+ 0.16
	19919.49	19918.99	— 0.50	+ 0.13
7	20814.61	20813.84	— 0.77	+ 0.18
	20818.31	20817.30	— 1.01	+ 0.23
	20820.39	20819.04	— 1.35	+ 0.31
8	21389.86	21389.62	— 0.24	+ 0.05
	21393.56	21393.97		
	21395.64			
9	21779.29	21780.17	+ 0.88	— 0.19
	21782.99	21784.49		
	21785.07			

The first constant has very nearly the same value for both series. The difference 14.08 corresponds to 2.6 Ångström units. We may well assume that they really end at the same place. According to the notations of Rydberg, and of Kayser and Runge, they are, therefore, to be considered as "secondary series." The stronger one we denote as the first, the weaker one as the second secondary series.

Rydberg's formula

$$A - B\,(n + \mu)^{-2}$$

also applies with much the same accuracy as the formula

$$A - Bn^{-2} - Cn^{-3}$$

to represent the wave-numbers of the two series. We find for the strongest component

First secondary series: $23207.96 - 110396\ (n - 0.02148)^{-2}$
Second secondary series: $23200.63 - 109011.3\ (n - 0.24127)^{-2}$

The differences between the observed and calculated values are, in Ångström units :

First Secondary Series.	Second Secondary Series.
− 0.02	+ 0.05
+ 0.07	− 0.15
− 0.03	+ 0.03
− 0.04	+ 0.13
− 0.01	+ 0.04
+ 0.06	− 0.10
− 0.02	

Rydberg's formula agrees a little better with the observed values, especially for the weaker series. And the first constant differs less for the two series.

Rydberg has expressed the opinion that a connection exists between the second secondary series and the principal series (which hitherto has only been found in the spectra of the alkalis). It may be stated thus. If

$$A_a - B\,(n + \mu)^{-2} \qquad (a = 1, 2, 3)$$

be the formulæ for the three components of the second secondary series, $n = 2$ being the smallest value for which the formula is positive, and if the values A, σ_1, σ_2, σ_3, are calculated from the equations

(1) $$A_a = B\,(1 + \sigma_a)^{-2}$$

(2) $$A = B\,(1 + \mu)^{-2}$$

then the principal series is given by the formula

$$A - B\,(n + \sigma_a)^{-2} \qquad (a = 1, 2, 3;\ n = 1, 2, 3 \ldots .)$$

The relative intensities of the three components for $a = 1, 2, 3$, should be the same in both series. If $a = 1$ corresponds to the

strongest component in the triplets of the secondary series, it also corresponds to the strongest component in the triplets of the principal series. It follows, therefore, that in the order of intensity the components are reversed. For if $A_1 < A_3$, then $A - B\,(1+\sigma_1)^{-2}$ is larger than $A - B\,(1+\sigma_3)^{-2}$.

To test Rydberg's suggestion, we calculated the first two triplets of the principal series and found the wave-numbers:

	$n=1$	$n=2$
Strongest component,	12042.39	24378.72
Middle component,	12038.69	24377.54
Weakest component,	12036.61	24376.87

If we take these calculated values to be only rough approximations, we may say that they correspond to the observed triplets near 7770 and 3947. These have the wave-numbers:

Strongest component,	12862.79	25325.59
Middle component,	12859.41	25324.43
Weakest component,	12856.65	25323.79

The differences in the wave-numbers of the components agree well enough with the differences of the calculated values to ascribe the deviations to errors of observation. In the red triplet the two weaker components give too large a difference; but this determination has little weight, as it was very difficult to see them with a slit narrow enough to separate them. But the mean of the two weaker components may be assumed to be determined more accurately, and here the distance from the strongest component has indeed very nearly the calculated value.

We therefore think that there is strong reason to believe these two triplets to be the first two members of the principal series. Rydberg's statements contain an approximation to the facts. But the statements are of unequal value. Equation (1) appears to be satisfied more closely than equation (2). Equation (1) may also be written thus:

$$A - A_a = A - B\,(1+\sigma_a)^{-2},$$

that is to say, the difference between the limits of the principal and secondary series are equal to the wave-numbers of the first triplet of the principal series. In this way the law has been formulated by Schuster,[1] who discovered it independently, without being acquainted with Rydberg's memoir. It is interesting to note that the wave-numbers of the three Fraunhofer lines that seem to coincide with the lines of the first principal triplet show the calculated differences of wave-number more accurately than our measurements of the oxygen lines. According to the readings in Higgs' Atlas we obtain the differences 3.69 and 1.97, while the means of the secondary triplets give 3.70 and 2.08. The deviation 0.11 corresponds to 0.07 Ångström unit, and lies within the limits of error caused by the inaccuracy of the reading. This adds to the evidence that the Fraunhofer lines are oxygen lines.

The final proof that the principal series has been found would be given by observing the subsequent members. The next triplet is expected to be contracted to a width of 0.09 A. U. and to lie near 3334. The following triplet would then be still narrower and lie somewhere near 3117. These lines we have not found. But it may be that the slope of intensity, which in principal series appears to be steeper than in the secondary series, causes our exposures to be insufficient. From the intensity of the triplet 3947 we should have expected to find subsequent members of the series.

Besides the series of triplets we have found two other series of lines. Probably all these lines are close doubles; for the four brightest we have seen double, and we have measured the components of the brightest of these four. The weaker component is on the more refrangible side. We should expect the two components to have the same difference of wave-numbers in all the doublets. But we could not confirm it, because the weaker components were too weak to be measured.

[1] SCHUSTER, *Nature*, **55**, 200.

STRONGER SERIES.

Wave-number = $21203.19 - 108793\ n^{-2} - 39825\ n^{-3}$.

n	Wave-length observed	Wave-number calculated	Wave-number observed	Difference	Corresponding difference of wave-length
4.....	7254.32	13781.36	13781.15	−0.21	+0.11
5.....	6046.56	16532.87	16533.81	+0.94	−0.35
6.....	5555.16	17996.79	17996.36	−0.43	+0.13
7.....	5299.17	18866.82	18865.72	−1.10	+0.31
8.....	5146.23	19425.52	19426.38	+0.86	−0.23
9.....	5047.88	19805.44	19804.89	−0.55	+0.14
10.....	4979.73	20075.43	20075.93	+0.50	−0.12

WEAKER SERIES.

Wave-number = $21210.98 - 110329.5\ n^{-2} - 2485\ n^{-3}$.

n	Wave-length observed	Wave-number calculated	Wave-number observed	Difference	Corresponding difference of wave-length
4.....	7002.48	14276.56	14276.78	+0.22	−0.11
5.....	5958.75	16777.92	16777.48	−0.44	+0.16
6.....	5512.92	18134.77	18134.27	−0.50	+0.15
7.....	5275.25	18952.11	18951.28	−0.83	+0.23
8.....	5130.70	19482.23	19485.20	+2.97	−0.78
9.....	5037.34	19845.48	19846.31	+0.83	−0.21
10.....	4973.05	20105.20	20102.89	−2.31	+0.57

Rydberg's formulæ for the same series are:

$$21205.56 - 109366.7\ (n - 0.16191)^{-2}$$
$$21211.11 - 110346.7\ (n - 0.01093)^{-2}$$

The agreement with the measured values is about the same. But it must be stated in favor of Rydberg's formula that the first constant as well as the second differs less for both series than in Kayser and Runge's formula.

The two series have apparently the same limit and must therefore be taken as a second pair of secondary series. It seems that there is a second principal series as well. If we calculate the formula

$$A - 109366.7\,(n+\sigma)^{-2}$$

according to Rydberg's law, from the formula of the secondary series

$$21205.56 - 109366.7\,(n - 0.16191)^{-2}$$

so that

$$21205.56 = 109366.7\,(1+\sigma)^{-2}$$

and

$$A = 109366.7\,(2 - 0.16191)^{-2}$$

we obtain for $n = 1, 2, 3$, the wave-numbers

11165.10
22148.96
26375.15

The first number corresponds to a wave-length in the ultra-red part of the spectrum, where observations do not exist. The other two numbers are not very different from the wave-numbers of the strong lines 4368.466 and 3692.586.

Wave-number calculated:	22148.96	26375.15
Wave-number observed:	22885.23	27073.96
Difference:	736	699

In the first principal series the corresponding differences were 820 and 947. We venture to think that these two lines belong to a second principal series, although we did not succeed in finding the subsequent lines. At the same time it must be mentioned that the calculated values are deduced from the stronger one of the two secondary series, while according to Rydberg the weaker series ought to be taken.

Plate II is from a drawing of the six series. They show a striking similarity to the six series that make up the spectrum of clèveite gas,[1] as they form two sets of three series each, each set resembling the spectrum of one of the alkali metals In our paper on the spectrum of clèveite gas we had suggested that it consisted of two elements corresponding to the two sets

[1] C. RUNGE and F. PASCHEN, this JOURNAL, January 1896.

of three series. This inference can no longer be upheld; for the same argument would hold good for oxygen, for the duplicity of which there is no chemical evidence.

II. SULPHUR.

One end of the vacuum tube was widened and filled with concentrated sulphuric acid. The rest of the arrangement has been described above. We heated the sulphuric acid until it evaporated and a little of it condensed in and in front of the capillary tube. We then waited until the water vapor, generated at the same time, was again absorbed and in the meantime generated oxygen and drew it through the tube. Immediately afterwards a spectrum of sulphur appeared, which so far as we know, has not been observed heretofore. It was pure, when the tube was recently made with clean material. After a while the second spectrum of hydrogen appeared, probably on account of organic impurities dissolved in the sulphuric acid. The principal lines of the new spectrum, though weak, were also to be seen when sulphur was heated in the tube and oxygen added to it, and also when hyposulphuric acid was introduced into the tube. In these two cases the band spectrum of sulphur prevails and it seems that the new spectrum requires the presence of oxygen. It is best obtained from sulphuric acid and even then it is improved by an atmosphere of oxygen.

NEW SPECTRUM OF SULPHUR.

Wave-length	Mean error	Number of determinations	Intensity	Remarks
4694.357	0.03	3	10	The differences of the three wave-lengths are more accurate than the absolute values.
4695.690			8	
4696.488			6	
5278.31	0.08	8	3	The differences of the three wave-lengths are more accurate than the absolute values.
5278.81			5	
5279.19			6	
5287.88		1	2	
5290.89	0.03		4	Coincides with an impurity, which is perhaps due to oxygen.
5295.86	0.08	3	4	
5372.82	0.05	6	2	
5375.98	0.04	6	3	
5381.19	0.04	6	4	
5444.58	0.08	2	2	
5449.99	0.05	2	3	
5498.38	0.05	6	3	
5501.78	0.03	6	4	
5507.20	0.03	6	5	
5605.52	0.06	4	3	
5608.87	0.03	5	4	
5614.48	0.07	5	5	
5697.02	0.03	6	6	
5700.58	0.02	6	7	
5706.44	0.01	6	8	
5879.79	0.03	2	1	
5883.74	0.04	3	2	
5890.08	0.01	2	2	
6042.17	0.01	2	5	
6046.23	0.05	2	6	
6052.97	0.01	2	7	
6173.77	0.11	2	1	
6176.01	0.01	2	1	
6395.10		1	1	
6396.90		1	1	
6403.70	0.04	4	2	
6408.32	0.02	4	3	
6415.68	0.02	5	4	
6536.55	0.06	3	1	
6538.82	0.08	3	1	
6743.92	0.18	3	5	
6749.06	0.08	4	6	
6757.40	0.05	4	7	
7242			2	The limit of error may be as high as 2 Ångstr. units.

The greater part of the lines of this list may be arranged in two series of triplets, which show a perfect analogy to the triplets of oxygen. The differences of wave-numbers of the three components of each triplet are again the same for all triplets, as far as the accuracy of the determination goes.

TRIPLETS.

Wave-length	Wave-number	Difference	Remarks
6757.40	14794.58		
		18.29	
6749.06	14812.87		
		11.29	
6743.92	14824.16		
6415.68	15582.57		
		17.90	
6408.32	15600.47		
		11.26	
6403.70	15611.73		
6052.97	16516.32		
		18.41	
6046.23	16534.73		
		11.12	
6042.17	16545.85		
5890.08	16973.07		
		18.29	
5883.74	16991.36		
		11.42	
5879.79	17002.78		
5706.44	17519.28		
		18.01	
5700.58	17537.29		
		10.97	
5697.02	17548.26		
5614.48	17806.23		
		17.81	
5608.87	17824.04		
		10.66	
5605.52	17834.70		
5507.20	18153.09		
		17.89	
5501.78	18170.98		
		11.24	
5498.38	18182.22		
5449.99	18343.64	18.23	The third component was not seen.
5444.58	18361.87		
5381.19	18578.17		
		18.01	
5375.98	18596.18		
		10.94	
5372.82	18607.12		
5295.86	18877.50		
		17.74	
5290.89	18895.24		
		10.76	
5287.88	18906.00		

The means of the differences are 18.15 and 11.13, taking account of the weights. We may now correct the components of each triplet, so that the corrected wave-numbers show these differences 18.15 and 11.13, while their center of gravity remains the same. The following list contains these corrected wave-numbers:

WAVE-NUMBERS.

Wave-number observed	Wave-number corrected	Difference	Corresponding deviation of wave-lengths	Mean error of the wave-length
14794.58	14794.63	+ 0.05	— 0.02	0.05
14812.87	14812.78	— 0.09	+ 0.04	0.08
14824.16	14823.91	— 0.25	+ 0.11	0.18
15582.57	15582.45	— 0.12	+ 0.05	0.02
15600.47	15600.60	+ 0.13	— 0.05	0.02
15611.73	15611.73	0.00	0.00	0.04
16516.32	16516.45	+ 0.13	— 0.05	0.01
16534.73	16534.60	— 0.13	+ 0.05	0.05
16545.85	16545.73	— 0.12	+ 0.04	0.01
16973.07	16973.12	+ 0.05	— 0.02	0.01
16991.36	16991.27	— 0.09	+ 0.03	0.04
17002.78	17002.40	— 0.38	+ 0.13	0.03
17519.28	17519.23	— 0.05	+ 0.02	0.01
17537.29	17537.38	+ 0.09	— 0.03	0.02
17548.26	17548.51	+ 0.25	— 0.08	0.03
17806.23	17805.84	— 0.39	+ 0.12	0.07
17824.04	17823.99	— 0.05	+ 0.02	0.03
17834.70	17835.12	+ 0.42	— 0.13	0.06
18153.09	18152.96	— 0.13	+ 0.04	0.03
18170.98	18171.11	+ 0.13	— 0.04	0.03
18182.22	18182.24	+ 0.02	— 0.01	0.05
18343.64	18343.66	+ 0.02	— 0.01	0.05
18361.87	18361.81	— 0.06	+ 0.02	0.08
18578.17	18578.04	— 0.13	+ 0.04	0.04
18596.18	18596.19	+ 0.01	— 0.00	0.04
18607.12	18607.32	+ 0.20	— 0.06	0.05
18877.50	18877.15	— 0.35	+ 0.10	0.08
18895.24	18895.30	+ 0.06	— 0.02	0.03
18906.00	18906.43	+ 0.43	— 0.12	— —

The two series appear to be secondary series. We have observed six triplets belonging to the stronger series, and only four of the weaker one. The wave-numbers are represented by the following formulæ:

FIRST SECONDARY SERIES.

Strongest line : $20086.89 - 109598\,n^{-2} - 113556\,n^{-3}$
Middle line : $20105.04 - 109598\,n^{-2} - 113556\,n^{-3}$
Weakest line : $20116.17 - 109598\,n^{-2} - 113556\,n^{-3}$

n	Wave-number calculated	Wave-number observed	Difference	Corresponding difference of wave-lengths
5	14794.52	14794.58	+ 0.06	— 0.03
	14812.67	14812.87	+ 0.20	— 0.09
	14823.80	14824.16	+ 0.36	— 0.16
6	16516.78	16516.32	— 0.46	+ 0.17
	16534.93	16534.73	— 0.20	+ 0.07
	16546.06	16545.85	— 0.21	+ 0.08
7	17519.13	17519.28	+ 0.15	— 0.05
	17537.28	17537.29	+ 0.01	0.00
	17548.41	17548.26	— 0.15	+ 0.05
8	18152.63	18153.09	+ 0.46	— 0.14
	18170.78	18170.98	+ 0.20	— 0.06
	18181.91	18182.22	+ 0.31	— 0.09
9	18578.06	18578.17	+ 0.11	— 0.03
	18596.21	18596.18	— 0.03	+ 0.01
	18607.34	18607.12	— 0.22	+ 0.06
10	18877.35	18877.50	+ 0.15	— 0.04
	18895.50	18895.24	— 0.26	+ 0.07
	18906.63	18906.00	— 0.63	+ 0.18

The formulæ of the first secondary series have been calculated by the method of least squares from the wave-numbers corrected to equal differences. The formulæ of the second secondary series have been calculated simply from the wave-numbers of the first three triplets corrected to equal differences.

For smaller values of n the formulæ of the first secondary series give two ultra-red triplets, of whose existence we know nothing. The second series also gives two triplets, of which one might just be visible being near 7700. We have looked for it, but could not detect it. However, it may well have escaped our attention, as the eye is not sensitive in this region, and the second series is the weaker one of the two.

SECOND SECONDARY SERIES.

Strongest line, $20078.37 - 108744.5\, n^{-2} - 18268\, n^{-3}$
Middle line, $20096.52 - 108744.5\, n^{-2} - 18268\, n^{-3}$
Weakest line, $20107.65 - 108744.5\, n^{-2} - 18268\, n^{-3}$

n	Wave-number calculated	Wave-number observed	Difference	Corresponding difference of wave-lengths
5	15582.45	15582.57	+ 0.12	— 0.05
	15600.60	15600.47	— 0.13	+ 0.05
	15611.73	15611.73	0.00	0.00
6	16973.12	16973.07	— 0.05	+ 0.02
	16991.27	16991.36	+ 0.09	— 0.03
	17002.40	17002.78	+ 0.38	— 0.13
7	17805.84	17806.23	+ 0.39	— 0.12
	17823.99	17824.04	+ 0.05	— 0.02
	17835.12	17834.70	— 0.42	+ 0.13
8	18343.56	18343.64	+ 0.08	— 0.02
	18361.71	18361.87	+ 0.16	— 0.05
	....	.....	.....	.....

From the analogy with the spectrum of oxygen, we should expect a principal series of triplets, for which the differences of wave-numbers become smaller for smaller wave-lengths and for which the components are in the inverse order of intensity. According to Rydberg's law, found to give a rough approximation to the facts in the case of oxygen, we may calculate the formulæ for the principal series.

For Rydberg's form the formulæ of the second secondary series are :

Strongest line, $20078.95 - 108868.5\, (n - 0.07945)^{-2}$
Middle line, $20097.10 - 108868.5\, (n - 0.07945)^{-2}$
Weakest line, $20108.23 - 108868.5\, (n - 0.07945)^{-2}$

From these we obtain for the principal series :

Strongest line, $29515.56 - 108868.5\, (n + 0.32852)^{-2}$
Middle line, $29515.56 - 108868.5\, (n + 0.32747)^{-2}$
Weakest line, $29515.56 - 108868.5\, (n + 0.32683)^{-2}$

The triplet corresponding to $n = 2$ is in the ultra-red, but for $n = 3$ we get

		Difference
Strongest line,	19689.05	
Middle line,	19682.84	6.21
Weakest line,	19679.05	3.79

In the case of oxygen the values calculated in this manner showed only a rough approximation to the observed wave-numbers. The latter were considerably larger. But the differences of the three components agreed well with the observed differences. Bearing this in mind, it does not seem improbable that the strong triplet near wave-length 4695 is a member of the principal series:

	Wave-length	Wave-number	Difference
Strongest line,	4694.357	21296.32	6.05
Middle line,	4695.690	21290.27	3.61
Weakest line,	4696.488	21286.66	

As we have shown above, Rydberg's rule of calculating the formulæ of the principal series may be separated into two equations. One of them is only roughly satisfied, while the other is in close accordance with the facts. Schuster has formulated it thus: the difference between the wave-numbers of the units of the principal series and the secondary series is equal to the wave-numbers of the first member of the principal series. If we neglect the first equation and keep only the second, we have one constant of the formula at our disposal, which we may determine to make the observed triplet the second member of the principal series.

Thus we obtain the formulæ

Strongest line, $31123.00 - 108868.5\ (n+0.32852)^{-2}$
Middle line, $31123.00 - 108868.5\ (n+0.32747)^{-2}$
Weakest line, $31123.00 - 108868.5\ (n+0.32683)^{-2}$

These give for the following value of n the wave-lengths (in air):

3949.54, 3949.98, 3950.25

which, however, we have no more been able to observe than the corresponding triplet in the spectrum of oxygen. It may be

that the intensity in the principal series decreases so rapidly that this triplet becomes imperceptible.

It seems only probable that in the spectrum of sulphur the other three series of oxygen should also find their analogy. We have, however, not succeeded in finding them. Possibly the strong triple line near 5279 corresponds to the oxygen line 4368. The latter would then also have to be a triplet, but so close that it might be rather difficult to separate the components. For if we compare the differences of wave-numbers in the triplets of oxygen with those of sulphur we see that they increase about in the proportion of 1 to 5. If therefore the oxygen line 4368 corresponded to the sulphur triplet 5279, we would expect 4368 to be a triplet of one-fifth the width.

III. SELENIUM.

If instead of sulphuric acid we introduce concentrated selenious acid[1] into the vacuum tube and treat it in a similar way as described above, there appears a spectrum of selenium, which as far as we know has not been observed heretofore. Selenious acid must be heated somewhat stronger than sulphuric acid before the vapor condenses in the capillary tube and gives a bright spectrum. But the spectrum tube keeps better than that of sulphur. An atmosphere of oxygen seems to increase its visibility in the same way as that of sulphur. Many lines of the selenium spark spectrum appear at the same time with the new spectrum. This is also the case with oxygen and sulphur. We have observed many, though not all of the lines of the selenium spark spectrum found by Plücker and Hittorf. They are not contained in the following table. Our attention was principally directed to the new spectrum, which mainly consists of triplets. Sometimes for short periods this alone was visible together with the oxygen and hydrogen lines. But we could not keep the tube in this state. For this reason our photographs, which had

[1] We concentrated the commercial dilute selenious acid by letting it slowly evaporate, so that in vacuo it did not give off any water-vapor.

to be exposed for some time on account of the small intensity of some of the lines, do not show the spectrum free from impurities. Of the red lines we could only measure the stronger ones. The weaker ones are not contained in the following table except a few weak lines that are near to measured lines so that their wave-lengths could be estimated without micrometrical measurement.

NEW SPECTRUM OF SELENIUM.

Wave-length	Mean error	Number of determinations	Intensity	Remarks
4731.04	0.07	5	10	The differences between the wave-lengths of the components in these two triplets are more accurate than the absolute values.
4739.28		5	9	
4742.52		5	8	
5365.59	0.03	4	8	
5370.04		4	10	
5374.27		4	10	
5464.82	0.15	3	3	
5497.06	0.11	3	3	
5528.64	0.05	3	4	
5618.05	0.08	3	5	
5652.62	0.04	2	3	
5666.95	0.03	3	3	
5700.32	0.07	2	3	
5703.86	0.05	4	4	
5705.18	0.05	4	3	
5718.28	0.03	4	7	
5718.5			1	The distance from the preceding line was estimated.
5752.31	0.09	3	2	
5753.52	0.04	4	7	
5827.90	0.06	2	1	
5843.10	0.05	4	2	
5866.53	0.10	3	2	
5878.88	0.06	4	2	
5907.10	0.03	2	2	
5909.49	0.02	4	3	
5925.13	0.02	4	4	[mated.
5925.31			1	The distance from the preceding line was esti-
5961.7			1	The distance from the following line was esti-
5962.08	0.03	4	5	mated.
6121.95	0.15	4	2	
6135.52	0.09	3	1	
6138.51	0.09	5	2	
6177.87	0.10	5	3	
6266.36	0.06	4	4	
6269.28	0.09	3	3	

NEW SPECTRUM OF SELENIUM (*continued*).

Wave-length	Mean error	Number of determinations	Intensity	Remarks
6283.54	0.06	3	2	
6284.19			1	The distance from the neighboring lines was estimated.
6284.51	0.07	4	3	
6325.4			1	The distance from the following line was estimated.
6325.81	0.03	4	6	
6679.72	0.10	4	5	
6699.78	0.06	5	6	
6701.29	0.03	2	1	
6746.65	0.07	5	6	
6831.28	0.24	3	5	
6990.96	0.06	6	4	Double ?
7010.84	0.12	5	3	
7014.24	0.09	5	3	
7062.14	0.06	5	5	

It is not impossible that some of the weaker lines contained in this list belong to the spark spectrum. The greater part form two series of triplets which do not appear in the spark-spectrum and are similar to the series of triplets in the spectra of oxygen and sulphur.

The constant differences between the wave-numbers of the components are not so easily shown as with the two elements of smaller atomic weight. It appears that some of the components of the triplets are accompanied by weak satellites, and that these, not the main lines, show the constant differences of wave-number. Something quite similar has been observed with the first secondary series in the spectra of calcium, strontium, zinc, cadmium, and mercury. The weak satellites are not so easily measured, and may sometimes escape the attention of the observer. We are therefore disposed to believe that the deviations from the constant difference of wave-numbers may disappear with a more complete and more accurate determination of the components.

TRIPLETS.

Wave-length	Wave number	Differences	
7062.14	14156·17		
			103.56
7014.24	14252.84		
			47·47
7010.84	14259.76		
			40.55
6990.96 d ?	14300.31		
6746.65	14818.15		
			103.66
6701.29	14918.45		
			48.18
6699.78	14921.81		
			44.82
6679.72	14966.63		
6325.81	15803.95		
			103.85
6325.4	15804.98		
			103.64
6284.51	15907.80		
			45.27
6284.19	15908.62		
			43.62
6283.54	15910.27		
			103.76
6269.28	15946.45		
			44.05
6266.36	15953.89		
6177.87	16182.41		
6138.51	16286.17		
6121.95	16330.22		
5962.08	16768.10		
			104.05
5961.7	16769.17		
			103.50
5925.31	16872.15		
			45.18
5925.13	16872.67		
			41.66
5909.49	16917.82		
5878.88	17005.41		
5843.10	17109.54		
5827.90	17154.16		
5753.52	17375.92		
			106.41
5752.31	17379.58		
			102.75
5718.5	17482.33		
			103.42
5718.28	17483.00		
5705.18	17523.15		
			44.20
5703.86	17527.20		
5700.32	17538.09		
5666.95	17641.37		
			44.72
5652.62	17686.09		
5528.64	18082.66		
			103.88.
5497.06	18186.57		

[1] The third line has not been observed.

It is not feasible to correct the wave-numbers so as to make the differences constant. For one does not know how to shift the weak satellites. Nevertheless, it may be satisfactorily shown that there are two series of triplets, as Plate II indicates.

The satellites are not drawn on account of the small scale. The dotted lines are not observed; they merely serve to emphasize the symmetry of the distribution.

In order to show that both series may be represented by formulæ, showing the characteristics of series, it is sufficient to take one line only of each triplet. For the triplets without satellites we take the least refrangible line; for the others the least refrangible satellite. The formulæ have been calculated from three lines only without the method of least squares. On account of the uncertainty of the satellites, it is of no use to employ this method.

First (stronger), secondary series:

$$\text{Wave-number} = 19266.54 - 108900.6n^{-2} - 94293n^{-3}$$

n	Wave-number calculated	Wave-number observed	Difference	Remarks
5	14156.17	14156.17	0.00	These three values determine the constants.
6	15804.98	15804.98	0.00	
7	16769.17	16769.17	0.00	
8	17380.80	17379.58	— 1.22	
9	17792.74	17794.91	+ 2.17	
10	18083.24	18082.69	— 0.55	
11	18295.69	18293.89	— 1.80	

The fifth wave-number, 17794.91, corresponds to the wave-length 5618.05. The other two components would be strong enough to be seen, but they are lost in one of the two green oxygen bands. It is not unlikely that there is a satellite to 5618.05. That would explain the unsystematic deviation of the formula. The last wave-number corresponds to the wave-length 5464.82. The other two components of the triplet have not been observed. Perhaps the line 5416.94 (intensity 1), wave-number 18455.57 (observed once only), belongs to the next

triplet. The calculated value is 18455.72. But the line may also be an impurity.

Second (weaker), secondary series:

Wave-number = $19286.72 - 111959.6n^{-2} + 1227n^{-3}$

n	Wave-number calculated	Wave-number observed	Difference	Remarks
5	14818.15	14818.15	0.00	These three values determine the constants.
6	16182.41	16182.41	0.00	
7	17005.41	17005.41	0.00	
8	17539.75	17538.09	− 1.66	

The smaller values of n correspond to lines in the ultra-red, which have not been observed. The second series has also been calculated in Rydberg's form:

$$19286.76 - 111963.9\ (n + 0.00556)^{-2}$$

If we take the differences of the wave-numbers of two subsequent components to be 103.71 and 44.55, the other components are represented by the formulæ:

$$19390.47 - 111963.9\ (n + 0.00556)^{-2}$$
$$19435.02 - 111963.9\ (n + 0.00556)^{-2}$$

According to Rydberg's rules, we find for the principal series:

$$\frac{111963.9}{(2.00556)^2} - 111963.9\ (n + \sigma_\alpha)^{-2} \quad (\alpha = 1, 2, 3),$$

where σ_1, σ_2, σ_3 have to be determined in such a manner that $111963.9\ (n + \sigma_\alpha)^{-2}$ assumes the values 19286.76, 19390.47, 19435.02.

We find in this way:

Strongest line, $27835.99 - 111963.9\ (n + 0.409403)$
Middle line, $27835.99 - 111963.9\ (n + 0.402951)^{-2}$
Weakest line, $27835.99 - 111963.9\ (n + 0.400195)^{-2}$

For $n = 2$ the lines are in the ultra-red, but for $n = 3$ we obtain:

		Difference
Strongest line, - - - -	18203.99	
		36.56
Middle line, - - - -	18167.32	
		15.68
Weakest line, - - - -	18151.64	

We expect these absolute values to be only rough approximations, but the differences we should expect to be in close accordance with the facts.

In the spectrum of oxygen and sulphur the observed wave-numbers of the corresponding triplet were considerably larger than the calculated values. Therefore we think it very likely that the strong triplet near 4740 is the triplet in question. We have:

	Wave-length	Wave-number	Difference
Strongest line, - - -	4731.04	21131.19	
			36.77
Middle line, - - -	4739.28	21094.42	
			14.37
Weakest line, - - -	4742.52	21080.05	

The differences are in good accordance with the expected values and so are the intensities. The strongest line and weakest line have reversed their position, as should be the case, the strongest component in the principal series now being the most refrangible, while it is the least refrangible in the secondary series. We have not observed further members of the principal series. The next triplet would be expected near 4000. The differences of the wave-lengths of the components would have to be about 2.7 and 1.2 Ångström units. If the assumption of the principal series is correct, the intensity would have to decrease very rapidly to cause this triplet to become imperceptible.

Whether the strong selenium triplet near 5370 corresponds to the oxygen line 4368 and the sulphur triplet near 5280 we cannot say. Its position makes it seem probable. But we should expect the components to be closer to one another and the relative position of the components is not similar to that of the components of the sulphur triplet near 5280.

Comparing the three spectra of oxygen, sulphur, and selenium, there are a few features that force themselves on our atten-

tion. The differences between the wave-numbers of the three components are the smallest in the spectrum of oxygen and the largest in the spectrum of selenium. They increase with increasing atomic weight, roughly proportional to the square of the atomic weight.

	Difference of wave-numbers	Atomic weight	Square of atomic weight divided by difference of wave-numbers
O, - -	3.70 and 2.08	16	69 and 123
S, - -	18.15 and 11.13	32.06	57 and 92
Se, - -	103.7 and 44.6	79.07	60 and 140

The same thing has been observed with the doublets in the spectra of the alkali metals and with the triplets in the spectra of magnesium, strontium, calcium, and of zinc, cadmium, and mercury.

On the whole the spectrum of selenium consists of lines of longer wave-lengths than that of sulphur, and this again of longer wave-lengths than that of oxygen. The greater atomic weight corresponds to slower oscillations. The same has been observed in the spectra of other groups of chemically related elements.

We tried in vain to produce the spectrum of tellurium in the vacuum tube. We introduced telluric acid, which Professor Seubert was so kind as to make for us, into the vacuum tube and treated it as we had treated the sulphuric acid and the selenious acid. But it appears that the temperature to which we could expose the evacuated glass tube was not high enough to evaporate the telluric acid and make it condense in the capillary tube. At all events we did not discover any lines belonging to tellurium.

ADDENDUM.

For the determination of the red lines in the three spectra we have used argon lines as standards. But as the red argon lines have not hitherto been determined accurately enough, they had first to be measured. We have determined their wave-

lengths by measuring their position relatively to the lines of the solar spectrum that are contained in Rowland's list of standard wave-lengths. An image of the Sun was thrown on the slit alternately with the light of the argon vacuum tube, care being taken that each time the same part of the slit was illuminated and that the whole ruled surface of the grating was filled with light. The distances of the lines were measured with an Abbe comparator, on the movable part of which we fastened a microscope of low power. In a similar way the wave-lengths of the red oxygen, sulphur and selenium lines were measured with the argon lines as standards. We also determined the wave-lengths of argon with a small, flat grating on a spectroscope of the old type by measuring the angles through which the grating is turned to bring the different lines on the cross hairs. These measurements, however, have only small weight compared with the measurements with the concave grating.

A number of weaker argon lines have occasionally been measured without having been used as standards. They are included in the following list and may be distinguished from the lines used as standards by the omission of their mean error, which we suppose to be somewhat larger than the mean error of the lines used as standards. The different determinations have been made on different days. The lines marked *r* (red) we have observed to disappear when a spark gap is interposed in the circuit. They belong to the red spectrum of argon exclusively. The lines marked *r* and *b* (red and blue) we have observed to remain when a spark gap is interposed. The lines marked *b* (blue) were seen only with a spark gap. They belong to the blue spectrum exclusively. This latter class has not been measured accurately. Nevertheless we include them in the list. The intensity is estimated by the numbers 1 to 10, the larger number signifying greater intensity. In the fifth column we give the wave-lengths as they were determined by Kayser.

LINES OF ARGON.

Wave-length	Intensity	Number of different determinations	Mean errors	Kayser	Remarks
5860.54	4			5860.6 r	Eder and Valenta : 5860.69
5864.29	<1				
5870.52	1				
5880.41	<1				
5882.88	4			5882.78 r	Eder and Valenta : 5883.03
5888.79	6	4	0.011	5888.93 r	Eder and Valenta : 5889.02
5897.75	<1				
5900.70	<1				
5904.09	<1				
5912.31	7	4	0.014	5912.22 r	Eder and Valenta : 5912.48
5916.84	3				
5920.04	<1				
5920.33	<1				
5927.34	3	3	0.015		Eder and Valenta : 5928.61
5929.06	6	3	0.015	5928.5 r	
5941.08	3				
5942.92	5	3	0.02	5943.5 r	
5949.47	3				
5960.78	<1				
5964.70	3				
5968.58	3				
5971.91	4	2	0.002		
5982.22	2				
5987.61	5	2	0.003	5987.5 r	
5994.99	2				
5999.29	4	2	0.01	5999.5 r	
6005.95	3	2	0.02		
6011.59	1				
6013.94	4	2	0.00	6013.6 r	
6015.40	<1				
6017.66	1				
6025.40	4	4	0.014	6025.8 r	
6032.39	9	4	0.017	6031.5 r	Double? Eder and Valenta: 5860.69
6035.49	<1				
6040.46	<1				
6043.48	8	4	0.02	6043.0 r	Eder and Valenta : 5928.61
6052.96	6	3	0.01	6052.7 r	
6059.62	7	4	0.02	6059.5 r	
6064.93	3	2	0.02		
6067.48	<1				
6075.20	<1				Double?
6081.50	2				
6085.90	1				
6090.97	4	3	0.06		
6093.44	1				
6096.09	1				
6099.03	6	4	0.016	6098.8 r	
6101.33	3	3	0.03		
6104.71	3				
6105.87	6	4	0.023	6106.1 r	

LINES OF ARGON (*continued*).

Wave-length	Intensity	Number of different determinations	Mean errors	Kayser	Remarks
6113.55	3	2	0.06		
6115.05	2			6114.1 b	
6119.74	3				
6121.93	2				
6123.8	<1				b
5125.96	1				
6127.57	4	4	0.03		
6129.02	3				
6134.12	<1				
6135.63	1				
6139.1	1			6140.9 b	b
6143.16	1				
6145.64	6	5	0.014	6145.6 r	
6155.46	5	3	0.014	6155.2 r	
6159.60	1				
6161.68	2				
6165.30	3				
6170.39	5	4	0.035	6170.3 r	
6172.7	5			6172.3 b	b
6173.32	6	4	0.03	6172.9 r	r and b
6179.50	2				
6183.12	<1				
6186.52	<1				
6189.5	<1				b
6194.25	<1				
6197.30	<1				
6199.44	<1				
6212.73	6	3	0.01	6212.5 r	
				6215.6 b	
6216.14	6	3	0.01		
				6217.5 r	
6224.85	1				
6230.96	2				
6235.99	1				
6238.58	<1				
6240.5	<1				b
6243.45	3			6243.7 b	b
6248.65	4				
6259.58	<1				
6266.70	1				
6278.80	2				
6297.15	5	4	0.012	6296.8 r	
6299.01	<1				Doubtful ?
6307.91	5	4	0.003	6307.8 r	
6309.36	1				
6334.24	<1				Uncertain.
6365.02	3				
6369.74	4			6368.0 r	
6384.89	5	4	0.04	6384.5 r	r and b
6402.21	1				

LINES OF ARGON (*continued*).

Wave-length	Intensity	Number of different determinations	Mean error	Kayser	Remarks
6416.54	8	4	0.014	6415.2 r	r and b
6431.77	3				
6466.65	3				
6481.17	2				
6483.6	3			6482.8 b	b
6494.10	2				
6513.87	1				
6538.43	3	3	0.04		r and b
6605.05	4	3	0.01		
6615.2	<1				b
6632.07	1				
6638.7	2			6638.6 b	b
6640.5	1				b
6644.3	3			6644.2 b	b
6660.92	3				
6664.27	3				r
6677.61	6	4	0.05	6676.5 r	r and b
6679.01	<1				
6682.7	2			6684.2 b	b
6684.95	<1				
6699.06	3				r
6719.33	2				
6753.15	5	4	0.02	6752.7 r	r and b
6756.58	1				
6766.97	1				r
				6786.5 r	
6827.85	<1				
6871.56	4	5	0.02	6870.6 r	r and b (weak)
6880.26	1				
6888.83	1				
6937.99	2	3	0.04	6937.8 r	r and b (weak)
6965.81	6	4	0.05	6964.8 r	r and b (weak)
7030.54	2	2	0.03	7029.2 r	r and b (weak)
7067.54	5	4	0.03	7066.6 r	r and b
7068.83	1				
7147.30	1	3	0.08	7146.8 r	r
7273.04	2	3	0.08	7271.6 r	r and b ?
7384.22	2	2	0.05	7383.9 r	r and b
7504.5	3			7503.4 r	r and b ?
7515.4	1			7515.1 r	r and b
7636.2	1			7635.6 r	r
7725				7723.4 r	The last two wave-lengths are only rough approximations, the error being perhaps as much as 2 A. U.
7952					

TECHNISCHE HOCHSCHULE,
Hannover, May 1898.

NOTES ON THE CONCAVE GRATING.

By S. A. MITCHELL.

I. FUNDAMENTAL FORMULA.

THE general theory of the concave spherical grating has been investigated by Rowland (*Phil. Mag.*, **16,** 1883; and *Amer. Jour. Sci.* (3), **26,** 1883); by Glazebrook (*Phil. Mag.*, **15,** 1883); by Mascart (*Jour. de Phys.* (2), **2,** 1883); by Baily (*Phys. Soc. Proc.*, **5,** 1883); and by Kayser (*Winkelmann, Handbuch der Physik*, p. 408).

The following treatment is one which starts from a general condition, true for every form of grating ruled with equal spaces along a chord. By introducing the condition that the form of the grating is the section of a sphere, the general equation of the concave grating is obtained.

From the general theory of gratings (Lord Rayleigh, "Wave Theory of Light," § 14, *Ency. Brit.*, p. 437; and Kayser, *Handbuch der Physik*), we know, if we have a grating ruled with equal spaces on any surface, that

$$\lambda = \frac{\omega}{N}(\sin\gamma + \sin\mu). \qquad (1)$$

where ω is the grating space, N the order of the spectrum, γ and μ the angles which the incident and diffracted light make with the normal to the surface at any point, and λ is the wave-length.

That is, in Fig. 1, if L is the radiant point, and a cone of rays from L falling on the surface of the grating QOT at P is brought to a focus at L' by any means (if the grating is plane a lens will be necessary), then λ is the wave-length of this light.

The above equation may be written:

$$(\sin\gamma + \sin\mu) = \frac{N\lambda}{\omega} \qquad (2)$$

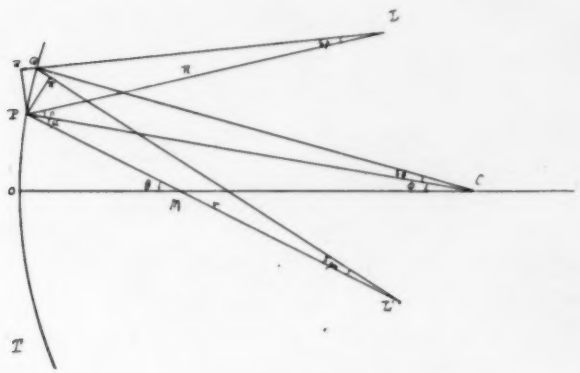


FIG. 1.

If now we allow the point P to move in the plane LoL', along the surface QOT, so that the angles which the incident and diffracted light make with the normal to the surface are now $(\gamma + \delta\gamma)$ and $(\mu + \delta\mu)$, then a new wave-length $(\lambda + \delta\lambda)$ will be brought to a focus at L', so as to satisfy the equation

$$\sin(\gamma + \delta\gamma) + \sin(\mu + \delta\mu) = \frac{N\lambda}{\omega} + \frac{\delta(N\lambda)}{\omega} \qquad (3)$$

Developing each term by Maclaurin's theorem, and subtracting (2), we get

$$\cos\gamma\, d\gamma - \tfrac{1}{2}\sin\gamma\,\delta\gamma^2 + \cos\mu\,\delta\mu - \tfrac{1}{2}\sin\mu\,\delta\mu^2 = \frac{1}{\omega}\delta(N\lambda) \qquad (4)$$

in which we neglect quantities of a higher order than the second. Hence, introducing an independent variable ϕ, we get:

$$\cos\gamma\frac{d\gamma}{d\phi} - \tfrac{1}{2}\sin\gamma\left(\frac{d\gamma}{d\phi}\right)^2 d\phi + \cos\mu\frac{d\mu}{d\phi} - \tfrac{1}{2}\sin\mu\left(\frac{d\mu}{d\phi}\right)^2 d\phi = \frac{1}{\omega}\frac{d(N\lambda)}{d\phi}.$$

This equation gives the change in wave-length due to a change in the angles of incidence and diffraction.

If now the surface is spherical — the case of Rowland's concave grating — O is the "center of the grating," C the center of curvature, CP is normal to the surface at P, and the line CP is the radius of curvature ρ. Then the angle LPC is equal to γ,

$L'PC$ is equal to μ, and putting OCP and OMP equal respectively to ϕ and θ, we see:

$$\gamma = \theta - \phi\,; \quad \mu = \theta' - \phi\,;$$

and hence,

$$\frac{d\gamma}{d\phi} = \frac{d\theta}{d\phi} - 1\,; \quad \frac{d\mu}{d\phi} = \frac{d\theta'}{d\phi} - 1 \tag{6}$$

Calling the distances LP and $L'P$ respectively R and r, we see that by letting fall perpendiculars PR and PR' on LQ and $L'Q$ respectively that

$$PR = \rho\, d\phi \cos\gamma = R\, d\theta.$$

Hence
$$\frac{d\theta}{d\phi} = \frac{\rho\cos\gamma}{R}$$

and consequently
$$\frac{d\gamma}{d\phi} = \frac{\rho\cos\gamma}{R} - 1\,.$$

Similarly,
$$\frac{d\mu}{d\phi} = \frac{\rho\cos\mu}{r} - 1\,. \tag{7}$$

Substituting these values of $\frac{d\gamma}{d\phi}$ and $\frac{d\mu}{d\phi}$ in equation (5) we get:

$$\cos\gamma\left(\frac{\rho\cos\gamma}{R} - 1\right) + \cos\mu\left(\frac{\rho\cos\mu}{r} - 1\right) \tag{8}$$

$$= \frac{1}{\omega}\frac{d(N\lambda)}{d\phi} + \frac{1}{2}\,d\phi\left\{\sin\gamma\left(\frac{\rho\cos\gamma}{R} - 1\right)^2 + \sin\mu\left(\frac{\rho\cos\mu}{r} - 1\right)^2\right\}$$

which equation is true to terms of the order $d\phi^2$. To have a perfect focus for waves of length λ at L', this change in wave-length due to a change in the angle ϕ must be zero, or in other words $\frac{d\lambda}{d\phi} = 0$. Light of wave-lengths which are whole multiples of λ will also be brought to the same focus at L', since

$$\frac{d(2\lambda)}{d\phi} = 0, \quad \frac{d(3\lambda)}{d\phi} = 0 \quad . \quad . \quad \text{etc.}$$

Hence making $\frac{d(N\lambda)}{d\phi} = 0$, and neglecting infinitely small quantities of the first order $(d\phi)$, we get:

$$\cos\gamma\left(\frac{\rho\cos\gamma}{R} - 1\right) + \cos\mu\left(\frac{\rho\cos\mu}{r} - 1\right) = 0 \tag{9}$$

It may be noted that the omitted term contains as a factor:

$$\sin\gamma\left(\frac{\rho\cos\gamma}{R}-1\right)^2+\sin\mu\left(\frac{\rho\cos\mu}{r}-1\right)^2. \qquad (10)$$

Equation (9) may be put in the form

$$\frac{\cos^2\gamma}{R}+\frac{\cos^2\mu}{r}=\frac{\cos\gamma+\cos\mu}{\rho}, \qquad (11)$$

whence we get:

$$r=\frac{R\rho\cos^2\mu}{R(\cos\gamma+\cos\mu)-\rho\cos^2\gamma}. \qquad (12)$$

This is the equation of the curve on which the spectra are brought to a focus. In this, the center of the grating is the origin, the line passing through the center of curvature is the axis of reference, R and γ the coördinates of the source of light, r and μ the coördinates of the spectral line.

This is the same equation as derived by Rowland (*loc. cit.*).

Further, we see that equation (11) is satisfied by making $R=\rho\cos\gamma$, $r=\rho\cos\mu$. The same substitution makes the omitted term, viz. (10), vanish. Consequently, if the conditions $R=\rho\cos\gamma$, $r=\rho\cos\mu$ are satisfied, formula (12) is true to terms of the second order. (See Kayser, *loc. cit.*) This condition is secured automatically in "Rowland's Mounting," where $R=\rho\cos\gamma$, $\mu=0$. Therefore $r=\rho$. (See Ames, *Johns Hopkins Circulars*, May, 1889.)

This mounting consists in having slit, grating, and camera at the vertices of a right angled triangle, the camera being placed at the center of curvature of the grating.

II. ASTIGMATISM.

One of the most important properties of a concave grating is its "astigmatism," *i. e.*, the fact that a point of light as a source gives rise to a focus, not a point, but a line. The advantages arising from this fact, as pointed out by Ames, (*Johns Hopkins Circulars*, May 1889) are:

1. A narrow spark at the slit is broadened out into a wide spectrum.

2. Greater accuracy in comparing metallic and solar lines.

3. No "dust lines," as they are brought to a different focus.

4. A spectrum is obtained which is broad enough to stand enlarging.

Although this property has always been recognized, no formula giving the amount of the astigmatism has ever been published, at least to my knowledge. This quantity is therefore deduced in the following pages.

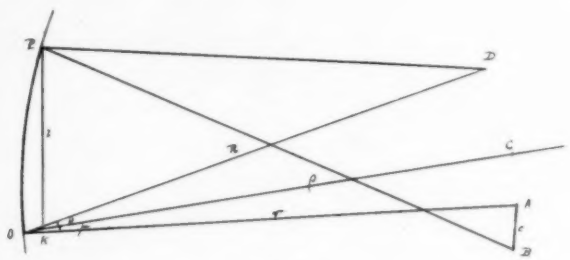


FIG. 2.

In Fig. 2 let D be the position of the point of light at the slit situated at a distance R from the center of the grating O; AB is the spectral line under consideration, which is consequently parallel to the lines of the grating, and is situated at a distance r from the center of the grating; C is the center of curvature; CO is the radius of curvature ρ. A, O, C, and D lie in a horizontal plane.

Let PO be a vertical section of the grating, *i. e.*, parallel to the lines of the grating. A small pencil of rays from the slit D falling on the grating at O is brought to a focus at A; a small pencil from D falling on the grating at P is brought to a focus at B. It is our problem to find the length of AB, assuming AB to be perpendicular to OA.

Call $AB = C$, $PK = Z$, where PK is the perpendicular let fall from P on the radius of curvature OC.

Since OK is a very small quantity compared with the other quantities considered :

$$OK = \frac{Z^2}{2\rho}, \text{ and}$$

$$AK = r - \frac{Z^2}{2\rho}\cos\mu.$$

$$BP^2 = AK^2 + (KP + AB)^2.$$

$$= (r - \frac{Z^2}{2\rho}\cos\mu)^2 + (Z + C)^2.$$

If we neglect terms of a higher order than the second we shall have:

$$BP = r - \frac{Z^2}{2\rho}\cos\mu + \frac{Z^2 + 2CZ + C^2}{2r}.$$

Similarly we shall have:

$$DP = R - \frac{Z^2}{2\rho}\cos\gamma + \frac{Z^2}{2R}.$$

But since the point of light at D and the focal line AB are true foci, the differences in paths of rays falling at P and at O must be zero. Hence

$$(AO + DO) - (BP + DP) = 0$$

$$i.e.\ \frac{Z^2}{2}\left(\frac{\cos\mu}{\rho} + \frac{\cos\gamma}{\rho} - \frac{1}{R} - \frac{1}{r}\right) - \frac{CZ}{r} - \frac{C^2}{2r} = 0. \quad (13)$$

Solving we get:

$$C = -Z \pm Z\sqrt{r\left(\frac{\cos\mu + \cos\gamma}{\rho} - \frac{1}{R}\right)}. \quad (14)$$

Twice this value will give us the length of the line, which is parallel to the lines of the grating, when we have a point-source of light at the slit. But in practice the illuminated portion of the slit, placed parallel to the lines of the grating, is of some finite length $2b$, where b is the length of the illuminated portion of the slit above the horizontal plane. To find the length (c') of the lines of the spectrum due to this, we have merely to apply the ordinary equation for finding the magnification due to a concave mirror:

$$\frac{C'}{r} + \frac{b}{R} = 0$$

$$\text{or } C' = -\frac{br}{R}$$

Adding this to the value from equation (14) we find half the length of the spectral lines :

$$C_0 = -Z \pm Z\sqrt{r\left(\frac{\cos\mu + \cos\gamma}{\rho} - \frac{1}{R}\right)} - \frac{br}{R}.$$

Where Rowland's mounting is used the photographic plate is at the center of curvature, and hence

$$r = \rho,$$
$$\mu = 0,$$
$$R = \rho\cos\gamma.$$

Substituting these values in the above equation we get

$$C_0 = -\frac{b}{\cos\gamma} - Z \pm Z\sqrt{1 - \frac{\sin^2\gamma}{\cos\gamma}}.$$

Taking the special case when $\gamma = 0$, the image of the slit coincides with the slit itself, and hence $C_0 = -b$. Whence we see that the positive sign before the radical must be used. Hence

$$C_0 = -\frac{b}{\cos\gamma} - Z + Z\sqrt{1 - \frac{\sin^2\gamma}{\cos\gamma}}. \qquad (15)$$

From this equation it is seen that the astigmatism depends only on the length of the slit, the length of the ruled lines of the grating, and the angle which the source of light makes with the axis of the grating. Astigmatism is *independent* of the radius of curvature.

In this formula C_0 is half the length of the spectral line, b is half the length of the illuminated portion of the slit, Z is half the length of the ruled lines of the grating. The angle γ is computed from the wave-length by the formula :

$\lambda = \frac{\omega}{N}(\sin\gamma + \sin\mu)$, which for the case of Rowland's mounting, where $\mu = 0$, reduces to

$$\lambda = \frac{\omega}{N}\sin\gamma.$$

Measuring the lengths of the lines of the spectrum formed by the large concave grating spectroscope used in the Johns

Hopkins University, we get the following table, giving the lengths measured and those computed from the above formula. The width of the spectrum was measured by holding a scale in front of the camera box and observing by means of an eyepiece held in the hand.

The grating has a radius of curvature of $21^{ft}.5$, is ruled with 20,000 lines to the inch, and has a ruled surface of 2^{in} by $5^{in}.66$. The length of the slit used was 3^{mm}. In the following table the first column gives the line of the spectrum, the second the wave-length (λ), the third the order of spectrum (N), the fourth the value of γ, the fifth the computed length of the spectrum line λ, and the sixth its observed length.

Line	λ	N	γ	Computed	Observed
h	4102	1	18°50′38″	6 mm	6mm
G	4308	1	19 49 44	6.5	7
F	4861.5	1	22 30 25	8	9
b_1	5184	1	24 5 28	8.5	11
D	5893	1	27 38 47	10	15
C	6563	1	31 6 57	12.5	17
B	6767	1	32 11 50	13	19
h	4102	2	40 14 22	21	29
G	4308	2	42 43 14	24	32
F	4861.5	2	49 57 34	46	51

Special case.—When the concave grating is used directly as a star spectroscope, the source of light is at infinity, and the slit-length is zero. In this case the fundamental equation (12) reduces to

$$r = \frac{\rho \cos^2 \mu}{\cos \gamma + \cos \mu} .$$

Hence, making $R = \infty$, and giving r this value, equation (14) reduces to

$$C = -2Z \sin^2 \frac{\mu}{2} .$$

The grating is used as a star spectroscope in two ways, either the photographic plate is in the axis of the grating, when $\mu = 0$ for the center of the plate, or the photographic plate is

placed so as to make $\gamma = 0$, *i. e.*, the light falls normally on the grating.

In the present work, with the direct grating spectroscope (see Poor and Mitchell, "The Concave Grating for Stellar Photography," this JOURNAL, March 1898), the large grating used had a ruled surface of 2^{in} by $5\frac{3}{4}^{in}$. The whole spectrum in the second order subtended an angle of about 6°. The grating was used in such a way that $\mu = 0$, at the center of the plate; and consequently for a variation of 3° in μ, the astigmatism amounted at most to $0^{in}.003$.

If the light (in the other method of using the grating) falls normally on the grating, *i. e.*, if $\gamma = 0$, then μ is about equal to 15°, and so the astigmatism amounts to about $0^{in}.07$.

Hence the grating used directly as a star spectroscope gives a spectrum which is exceedingly narrow.

III. FOCAL LINES.

By treating equation (13)

$$\frac{Z^2}{2}\left(\frac{\cos\gamma + \cos\mu}{\rho} - \frac{1}{R} - \frac{1}{r}\right) - C\frac{Z}{r} - \frac{C^2}{2r} = 0$$

in a slightly different way, some interesting results are obtained. The equation gives the position of the focus conjugate to a point source; C will be zero for either of two conditions:

$$Z = 0$$

$$\text{or} \quad \frac{\cos\gamma + \cos\mu}{\rho} - \frac{1}{R} - \frac{1}{r} = 0 \tag{16}$$

That is, under either of these conditions, the focus is a point, not a line.

The meaning of equation (16) will be better understood if we regard the grating from another standpoint. Using the grating in the ordinary way, a cone of rays falls obliquely on its surface, and is diffracted and brought to a focus in a spectral line.

Thus we may consider the grating as some sort of a mechanism which changes a pencil of rays falling obliquely on the grat-

ing into a pencil leaving at some different angle. This action may be considered in two ways, according as we take a meridian section of the grating, *i. e.*, a section passing through the two focal points and the center of the grating; or, as we take an equatorial section, *i. e.*, a section of the grating at right angles to this. The equations of oblique pencils refracted at a spherical surface of a medium whose index of refraction is p have been fully treated and discussed by Czapski (Winkelmann, *Handbuch der Physik*, **2**, 85, 86); and by Rayleigh (*Ency. Brit.*, **14**, 800, art. "Optics").

These equations give the position of the *focal lines* for a meridian section and for an equatorial section. They are:

$$\frac{\cos^2\gamma}{R} - \frac{p\cos^2\mu}{r} = \frac{\cos\gamma - p\cos\mu}{\rho}, \tag{17}$$

$$\frac{1}{R'} - \frac{p}{r'} = \frac{\cos\gamma - p\cos\mu}{\rho}, \tag{18}$$

where R and R' are the distances of the radiant point from a point in the meridian and equatorial sections respectively, r and r' are the distances of the focal lines from the same point of the surface, ρ is the radius of curvature, γ and μ are the angles which the incident and refracted rays make with the normal at the surface.

Applying this to the case of the concave grating by putting $p = -1$, we get

$$\frac{\cos^2\gamma}{R} + \frac{\cos^2\mu}{r} = \frac{\cos\gamma + \cos\mu}{\rho}, \tag{19}$$

$$\frac{1}{R'} + \frac{1}{r'} = \frac{\cos\gamma + \cos\mu}{\rho}. \tag{20}$$

Equation (19) fixes the positions of the radiant and focal lines for a meridian section; equation (20), the position for an equatorial section. As the grating is generally used, the meridian section becomes a horizontal one, the equatorial section a vertical one. Thus equation (19) means that, if we use a horizontal section of the grating—a section perpendicular to the lines of the grating—we get the position of the conjugate foci;

a vertical line at the slit with coördinates R and γ is brought to a focus on the photographic plate in a vertical line whose coördinates are r and μ. This is the same equation as Rowland's. Equation (20) (which is identical with equation (16) gives the position of the radiant and focal lines using a vertical section of the grating, *i. e.*, a section parallel to the lines of the grating. This equation is satisfied by making $r' = \rho \sec \mu$, $R' = \rho \sec \gamma$; or making $\mu = 0$ (as in Rowland's mounting) by $r' = \rho$, $R' = \rho \sec \gamma$. From the theory of these focal lines (see *Ency. Brit., loc. cit.*) we see that corresponding to a point-source this focal line is horizontal, and conversely. Consequently, using a horizontal slit at a distance $\rho \sec \gamma$, and the angle γ from the grating, light from it, after passing through the vertical slit, will be brought to a focus in a point in the spectrum. This fact is shown by placing the source of light at some distance in front of the slit (*i. e.*, away from the grating), and by placing an obstacle, for example a knitting needle, horizontally in front of the vertical slit and distant $\rho \sec \gamma$ from the grating. Doing this, we shall get a sharply defined horizontal line running across the spectrum. (See Sirks, *Astronomy and Astro-Physics*, **13**, 1894.)

JOHNS HOPKINS UNIVERSITY.

Minor Contributions and Notes.

THE HYDROGEN ATMOSPHERE SURROUNDING THE WOLF-RAYET STAR D. M. +30°3639.

WHILE examining various star spectra with the 36-inch refractor on the night of June 28, I was much interested in confirming Professor Campbell's discovery of a hydrogen envelope around the Wolf-Rayet star *DM.* +30°3639.[1] With the collimator adjusted so that the spectrum was linear at *Hβ*, and with the slit wide, the *Hβ* line appeared as a circular, fairly well defined disk, which narrowed to a fine line crossing the linear star spectrum when the slit was closed up.

That this appearance is not an illusion of any kind produced, for example, by irradiation, is proved by the following experiments. (1) When the the spectrum is made linear at the blue band λ 4652, which is nearly as bright as *Hβ*, no such appearance as that described above is observed. The band is reduced to a mere line coincident with the star spectrum. This band is not much narrowed by closing the slit. (2) With the collimator adjusted so as to make the spectrum linear at *Hβ* and with the slit narrow, the star can be thrown off the slit by slightly displacing the telescope in declination, so that the continuous spectrum disappears. The short and narrow *Hβ* line remains visible, however, until the slit is displaced by more than the radius of the hydrogen envelope. This latter experiment, in particular, seems to be conclusive as to the reality of the observed phenomenon.

With a large reflector I think that this hydrogen envelope could be observed visually without a spectroscope, perhaps with the aid of a piece of blue glass. With a refractor the small disk is confused with the circles of chromatic aberration when the focus is adjusted for *Hβ*.

The existence of such an extensive hydrogen envelope around a Wolf-Rayet star has an important bearing on theories of bright-line stars, as Mr. Campbell has already pointed out.

JAMES E. KEELER.

LICK OBSERVATORY,
July 6, 1898.

[1] *A. and A.*, **12**, 913, 1893; *A. N.*, 3200.

NOTE ON PROFESSOR WILSING'S ARTICLE ON THE EFFECT OF PRESSURE ON WAVE-LENGTH.[1]

J. WILSING has pointed out that radiation from a vibrator has the additional effect of lowering the natural frequency of vibration. In the case of a circular disk, backed by a spring and vibrating in air, we have the equation of motion ready to hand (Lord Rayleigh's *Sound*, **2**, 196).

$$\left(1+\frac{8\sigma K^3}{3M}\right)\ddot{\xi}+\frac{\sigma\pi f^2K^4}{2aM}\dot{\xi}+f^2\xi=0.$$

Here σ is the density of air.

M is the mass of the disk.

a is the velocity of sound.

R is the radius of the disk.

This may be written, in Wilsing's notation:

$$(1+\gamma)\ddot{\xi}+2K'\dot{\xi}+f^2\xi=0$$

where

$$\gamma=\frac{8\sigma K^3}{3M}$$

$$2K'=\frac{\sigma\pi f^2K^4}{2aM}$$

Now δf_1, the shift of the line due to radiation, is of the order γf.

Furthermore, there is a widening δf_2 due to the accompanying damping. The half-width of the line is of order K'.

But

$$\gamma f : K'=\frac{8\sigma f K^3}{3M} : \frac{\sigma\pi f^2K^4}{2aM}$$

$$=\frac{8}{3} : \frac{\pi f R}{2a}$$

This is of order $\lambda : R$, where λ is the length of the emitted waves.

Now the diameter of a molecule is small compared with the wave-length of visible light. Therefore, if we can regard the acoustical analogy as pertinent, we should expect that the effect of radiation in shifting a spectrum line will be great compared with its effect in widening the line.

CHARLES GODFREY.

TRINITY COLLEGE, CAMBRIDGE,
July 7, 1898.

[1] This JOURNAL, May 1898.

THE NOVEMBER METEORS.[1]

On the night of November 13, 1897, ninety-one meteors were observed at the Harvard College Observatory, and forty-seven meteors at an auxiliary station twelve miles south, the Blue Hill Meteorological Observatory. A discussion of these observations by Professor W. H. Pickering will be found in the *Annals* of this Observatory, Vol. XLI, No. 5. A much greater display of meteors is expected next year, and it is very important that a continuous watch should be kept during the two or three days in which the Earth is passing through the denser portion of the meteor stream. This can only be done by establishing a series of stations in various longitudes, so that during the entire time one or more of these stations shall fulfill the conditions that the radiant point shall be above the horizon and the Sun below. Correspondence is invited with astronomers and others willing to participate in this work, especially with those who will be in the less frequented longitudes. If the weather is favorable, and the plan here proposed is carried out satisfactorily, it is expected that all the observations will be discussed here, and published in the *Annals* of this Observatory. To secure the best results a uniform plan of work is essential. Maps and forms of record will be sent to all who early signify their readiness to take part in this work. The radiant point of the meteors indicated by the cross in the accompanying map, will not rise in this latitude until $10^h\ 30^m$, and twilight will interfere at about $5^h\ 30^m$ in the morning. As the shower sometimes begins before the predicted date, a watch should be kept on November 11 and 12, from 11 to 1 o'clock, and if many meteors are seen the observations described below, for November 13, should be made on these nights, and also on the nights following the shower.

Each observer is requested to devote his attention to the region within 25° of the radiant point, and included in the map, and to send the following data regarding his observations: Name of observer, location of station, post office address, time of beginning and ending of observations, interruptions by clouds or other causes, condition of sky, as clear, hazy, passing clouds, etc.

The observations most desired are those required to determine the frequency of the meteors. They are of extreme simplicity and

[1] *Harvard College Observatory Circular* No. 31.

need only care, system, and perseverance. Once an hour, or better once every half hour, observe and record the time during which ten meteors appear. This is most easily done by noting the time by a watch and at exactly the beginning of a minute looking at the sky, giving it undivided attention and counting the meteors seen, not including those appearing outside of the region covered by the map. If great numbers of meteors appear it may be better to count a larger number, as twenty, or even fifty. If the interval between the meteors is long, the number to be counted may be reduced. These observations should be repeated until dawn, or over as long an interval as possible. Between these observations the observer may rest, or may make special observations of individual meteors. Thus, when a meteor is seen, record the hour and minute, the brightness on a scale of stellar magnitudes,— 2, equals the brightness of Jupiter or Sirius; 0, Arcturus or Vega; 2, the Pole Star; 4, the Pleiades; 6, the faintest star visible; the color, B = blue, G = green, Y = yellow, W = white, and R = red; the class, L = Leonid, if path prolonged would pass through center of map, N = other meteors. Thus L 5 Y, $12^h\ 26^m$, indicates that a Leonid, magnitude 5, yellow in color, was seen at $12^h\ 26^m$. Find by trial beforehand how many seconds are required to make each record. Again, the path of each meteor may be marked upon the map by noting its position in relation to the adjacent stars. Such work can be done equally well elsewhere, and should not interfere with the hourly count mentioned above.

EDWARD C. PICKERING.

May 30, 1898.

STARS HAVING PECULIAR SPECTRA.[1]

A LIST of stars having peculiar spectra is given in the annexed table. With one exception, noted below, they were all discovered by Mrs. Fleming in her regular examination of the Draper Memorial photographs. The designation of the star, its approximate right ascension and declination for 1900, its catalogue magnitude, and a brief description of its photographic spectrum are given in the successive columns of the table. When the object is not a catalogue star its position, as derived from a photograph, is given in the notes following the table.

[1] *Harvard College Observatory Circular* No. 32.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m			
.....	0 54.2	−75° 32	..	Type III. Hydrogen lines bright. Variable.
+11° 305	2 9.6	+11 47	8.9	Type IV.
A. G. C. 4042	3 35.2	−55 43	8.2	Type III. Hydrogen lines bright? Variable.
.....	4 52.0	−67 6	..	Gaseous nebula. Gal. long. 244° 36′, lat. −36° 3′.
Z. C. 5h 418	5 12.3	−47 2	8.5	Type III. Hydrogen lines bright. Variable.
−12° 1453	6 17.1	−12 56	9.6	Gaseous nebula. Gal. long. 188° 54′, lat. −11° 1′.
−12° 1500	6 23.7	−12 59	7.7	Type I. *Hβ* bright.
+5° 1267	6 25.2	+5 57	7.1	Type I. *Hβ* bright.
−8° 1467	6 28.1	−8 48	8.5	Peculiar. Variable with small range.
+6° 1309	6 32.0	+6 14	6.5	Type I. *Hβ* bright. *H. P.* 1250.
.....	7 13.9	−13 3	..	Type V. Gal. long. 195° 30′, lat. +1° 11′.
−3° 1873	7 18.1	−4 0	9.2	Type IV.
−11° 1941	7 22.4	−11 31	8.9	Peculiar. Variable.
−17° 2442	8 15.2	−17 57	9.1	Type IV.
.....	9 6.1	−69 32	..	Gaseous nebula. Gal. long. 253° 6′, lat. −14° 50′.
....	9 13.5	−65 49	..	Type IV. Variable.
+60° 1246	10 8.3	+60 31	6.3	Type III. Peculiar. Variable.
A. G. C. 14145	10 17.2	−55 33	5	Type I. *Hβ* and *Hγ* bright. J Velorum.
A. G. C. 14686	10 40.1	−59 1	7	Type I. *Hβ* bright.
.....	10 42.6	−65 5	..	Type IV.
Z. C. 11h 129	11 2.9	−54 35	9	Type IV.
.....	11 55.3	−54 33	..	Type IV.
−4° 3199	11 59.6	−5 13	8.7	Type II. Variable.
.....	13 26.8	−61 48	..	Type V. Gal. long. 275° 30′, lat. −0° 18′.
.....	13 29.1	−61 45	..	Type V. Gal. long. 275° 46′, lat. −0° 18′.
.....	15 26.7	−71 34	..	Type I. *Hβ*, *Hγ*, *Hδ*, *Hε*, and *Hζ* bright.
Z. C. 18h 1935	18 35.2	−51 51	9	Type IV.
.....	19 47.0	−65 37	..	Peculiar.
.....	21 36.6	−65 30	..	Type IV.
−8° 5858	22 16.5	−8 7	8.5	Type III. Hydrogen lines bright? Variable.

$0^h\ 54^m.2$. Position for 1875, R. A. $= 0^h\ 53^m\ 22^s.4$, Dec. $= -75°\ 40'\ 30''$.

$4^h\ 52^m.0$. Position for 1875, R. A. $= 4^h\ 52^m\ 1^s.2$, Dec. $= -67°\ 7'\ 39''$. This object is *N. G. C.* 1714.

$7^h\ 13^m.9$. Position for 1855, R. A. $= 7^h\ 11^m\ 45^s.4$, Dec. $= -12°\ 58'\ 2''$.

$7^h\ 18^m.1$. In the *A. N.*, **118**, 259, Espin gives −3° 1886, mag. 8.7, as having a spectrum of the fourth type. −3° 1886 follows −3° 1873 $1^m.8$, south $0'.3$, and has a spectrum of the first type. Probably −3° 1873 was the object observed by Espin, but erroneously identified by him.

$7^h\ 22^m.4$. The spectrum of this star resembles that of a star of the

fourth type. The bands, however, are of shorter wave-length, and are, perhaps, identical with those of a star of the third type. The portion of the spectrum whose wave-length is less than $H\gamma$, 4341, is too faint to appear in the photographs.

$9^h\ 6^m.1$. Position for 1875, R. A. $= 9^h\ 5^m\ 50^s.3$, Dec. $= -69^\circ\ 25'\ 58''$.

$9^h\ 13^m.5$. Position for 1875, R. A. $= 9^h\ 12^m\ 59^s.8$, Dec. $= -65^\circ\ 42'\ 37''$.

$10^h\ 17^m.2$. The lines $H\beta$ and $H\gamma$ in this star have been found to be variable by Miss A. J. Cannon. On June 2, 1893, they were bright, and superposed on a broad dark band. On April 17, 1895, and March 17, 1896, these lines, like the other hydrogen lines, were dark.

$10^h\ 40^m.1$. The hydrogen lines in this star appear to be variable. On May 20, 1892, $H\beta$, $H\gamma$, and $H\delta$ were dark. On April 3, 1895, the line $H\beta$ was bright. On April 21, 1895, $H\beta$ and $H\gamma$ were bright. $H\zeta$ and $H\eta$ were dark, with the edge of greater wave-length apparently bright.

$10^h\ 42^m.6$. Position for 1875, R. A. $= 10^h\ 41^m\ 40^s.8$, Dec. $= -64^\circ\ 57'\ 20''$.

$11^h\ 55^m.3$. Position for 1875, R. A. $= 11^h\ 54^m\ 3^s.1$, Dec. $= -54^\circ\ 25'\ 24''$.

$13^h\ 26^m.8$. Position for 1875, R. A. $= 13^h\ 25^m\ 6^s.2$, Dec. $= -61^\circ\ 40'\ 30''$.

$13^h\ 29^m.1$. Position for 1875, R. A. $= 13^h\ 27^m\ 23^s.2$, Dec. $= -61^\circ\ 37'\ 4''$.

$15^h\ 26^m.7$. Position for 1875, R. A. $= 15^h\ 24^m\ 8^s.2$, Dec. $= -71^\circ\ 29'\ 26''$. This is the object whose position for 1900 is announced in *Astronomy and Astro-Physics*, **12**, 546, as R. A. $= 15^h\ 27^m.0$, Dec. $= -71^\circ\ 32'$. Its spectrum is there described as of the third type having also bright hydrogen lines, and consequently it was suspected of variability. Later and better photographs show that the spectrum is continuous, with the hydrogen lines $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, and $H\zeta$ bright, resembling that of η Carinae as seen with the same dispersion. The variability is not confirmed.

$19^h\ 47^m.0$. Position for 1875, R. A. $= 19^h\ 44^m\ 37^s.0$, Dec. $= -65^\circ\ 41'\ 9''$.

$21^h\ 36^m.6$. Position for 1875, R. A. $= 21^h\ 34^m\ 37^s.9$, Dec. $= -65^\circ\ 37'\ 28''$.

STARS RESEMBLING ζ PUPPIS.

Besides ζ Puppis, the additional lines due to hydrogen are present in the spectra of the first and second classes of stars of the fifth type (*A. N.* **127,** 1), and in the spectra of the first group of stars of the Orion type according to the classification of Miss Maury (*H. C. O. Annals*, **28,** 15). The lines whose wave-lengths are there given as 4200.3, 4542.7, are probably additional hydrogen lines, and the line 4685.4 probably coincides with the bright band in ζ Puppis. Miss A. J. Cannon, from a careful study of the Draper Memorial photographs of the bright southern stars, has added the following stars to those already known to contain these lines. In *A. G. C.* 17572 the lines 3925, 4027, 4202, and 4544 are present and dark. In the fifth type stars, *A. G. C.* 8631 and 22763, the lines 4027, 4202, and 4544, and the bands 4633 and 4688 are present and bright. In the fifth type stars, *A. G. C.* 10863, 22748, and 22843, the hydrogen lines 3925, 4027, 4202, and 4544 are present and dark, and the bands 4633 and 4688 are present and bright. The band 4633 is double in the last two stars, and also in *A. G. C.* 9311, 29 Canis Majoris.

EDWARD C. PICKERING.

June 21, 1898.

A CHROMOSPHERIC LINE NEAR K.

UPON nearly all plates of the spectrum of the Sun's limb, taken for my investigation of "The Rotation Period of the Sun, and the Motions of the Sun's Atmosphere" (in course of preparation for publication), there appears, more or less faintly against the shading of the K line, a chromospheric line at wave-length 3934.954.

This line is generally stronger upon the plates showing the double reversal of the K line the most distinctly, but there does not seem to be a complete correspondence, and upon plates taken over Sun-spots where the K line is very strongly reversed, there are no traces whatever of this chromospheric line.

In the second order spectrum of the grating used, the first order ghost of the K line falls not far from the place occupied by this line, and the suspicion that the line in question might be a ghost of the reversal of K was at first entertained, being rendered more probable by the nebulous character of the line. But the wave-length is somewhat different, being 3934.954, while the first order ghost (on a

second order spectrum plate) of the violet component of the reversal is at 3935.569, and the red component at 3935.983. Besides, there is no corresponding bright line on the violet side of K, and the wave-length of the chromospheric line is the same on plates of the second and third order spectrum, which would not be the case were it a ghost (the actual distance apart of ghosts and the central line being the same on plates of the first, second, and third order spectrum, but not the difference in wave-length).

The line in question does not occur except upon plates of the spectrum of the Sun's limb. In Shackleton's flash spectrum it is not distinguishable from the K line. Professor C. A. Young writes that upon looking up some photographs of his, taken some years ago, a similar line shows, but he thinks it undoubtedly a ghost of K. Probably upon his plates the line is mixed up with a ghost of K, but with my own plates there is no coincidence and no question whatever as to the chromospheric origin of the line.

LEWIS E. JEWELL.

PHOTOGRAPH OF THE SPECTRUM OF THE "FLASH" MADE BY PROFESSOR K. D. NAEGAMVALA AT THE ECLIPSE OF JANUARY 21, 1898.

PLATE I is a negative reproduction of the spectrum of the "flash" as photographed by Professor Naegamvala at the last solar eclipse. In a recent letter Professor Naegamvala, who was stationed at Jeur, gives the following details regarding the photograph.

"The flash was visually observed with a small direct-vision combination and the signal was given to expose. The exposure was made off and on by hand and must have taken half a second, and the signal must have been taken up also half a second after it was given.

"The photograph was taken on an Edward Isochromatic plate, with a six-inch Taylor-Cooke Triplet and two objective prisms, 45°, 8 ×6 inches face.

"The ultra-violet part of the spectrum is not as extensive as might have been thought, but this is evidently due to the absorption in the lens. On the original plate the spectrum is quite conspicuous from D_3 to $H\eta$.

"The definition is unfortunately not very good. This is due to

the very few opportunities I had of adjusting the instrument, it having arrived so late as the 11th of January."

In justice to the photograph sent by Professor Naegamvala it should be stated that the half-tone cut fails to bring out all the fine lines shown on the original. Perhaps the most interesting feature of the photograph is the prominence shown in two lines between H and *Hδ*, but invisible in H and K and the hydrogen lines.

NOTE ON NEW GASES IN THE EARTH'S ATMOSPHERE.

MESSRS. RAMSAY AND TRAVERS communicated to the Royal Society on June 3 a preliminary note on *Krypton*, the new element they have discovered in the air. From $750^{cu\ cm}$ of liquid air they succeeded in obtaining $26^{cu\ cm}$ of a gas which showed, in addition to a feeble argon spectrum, two brilliant lines, one at λ5869 (very near the D_3 line), and the other at λ5570, with a fainter line at λ5557. The separation of the other lines from those of argon was difficult, but those lines were assigned to the new gas which were invisible or very faint in the argon spectrum when the two spectra were simultaneously compared. The approximate wave-lengths are

λ4317	λ4807	λ5557
4387	4830	5570
4461	4834	5829
4671	4909	5869 D_4
4736		6011

The density of the sample was found to be about 23, but the discoverers venture to conjecture that the density of the pure gas will turn out to be 40, with an atomic weight of 80, thus falling into the helium series. By the comparison of the length of a sound wave in it and in air, krypton is shown to be monatomic and simple.

Sir William Huggins had privately called our attention to the coincidence of the line at λ5570 with the principal line of the aurora, as has also been noted by Schuster and by Berthelot. Thus it seems that at last the true origin of that hitherto perplexing line has been discovered.

At the meeting of the Royal Society on June 16, Professor Ramsay announced the presence in atmospheric argon of two new companion gases, to which he has assigned the names *neon* and *metargon*.

The spectrum of neon is described as containing a large number of strong lines in the red, orange, and yellow, and in the deep violet. For the line at λ5850, near the helium line D_3 (λ5876) and the krypton line D_4 (λ5869), the designation D_5 is suggested. The density of the sample was about 14.

The density of metargon is given as 19.87, that of argon being 19.94. Its spectrum showed numerous bands, the wave-lengths of which are closely coincident with those in the band spectrum of carbon, with three cyanogen bands, as was promptly pointed out by Schuster (*Nature*, **58**, 199, June 30). Thus the spectroscopic evidence is strong that metargon is not a new element, but some form of carbon. In a subsequent number of *Nature* (July 14) Messrs. Ramsay, Travers, and Baly cite several chemical tests tending to exclude the possibility of carbon from the supposed new gas, and consider that these facts will necessitate a suspension of judgment on the question.

At the session of the French Academy on June 13, a sealed package, deposited in May 1896, was opened and the paper enclosed was presented by its authors, Messrs. Moissan and Deslandres. While experimenting in 1896 on the gases obtained from the mineral *cerite* they found a residual gas which showed lines of helium and argon and lines hitherto unknown, at λ4151.7, 4143.7, 4110.0, 4108.0, 4100.5.

They expressed the opinion that these were either new nitrogen lines, peculiar to low pressure, or else were due to a new atmospheric gas resembling nitrogen in chemical characteristics—with a preference for the latter view. M. Moissan now states the belief that the lines are not due to krypton. E. B. F.

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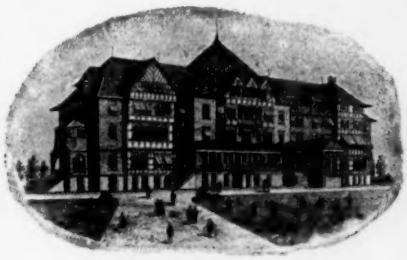

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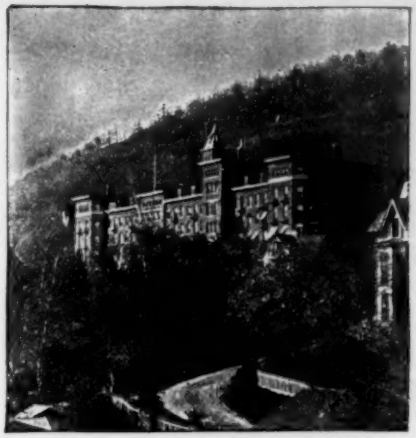

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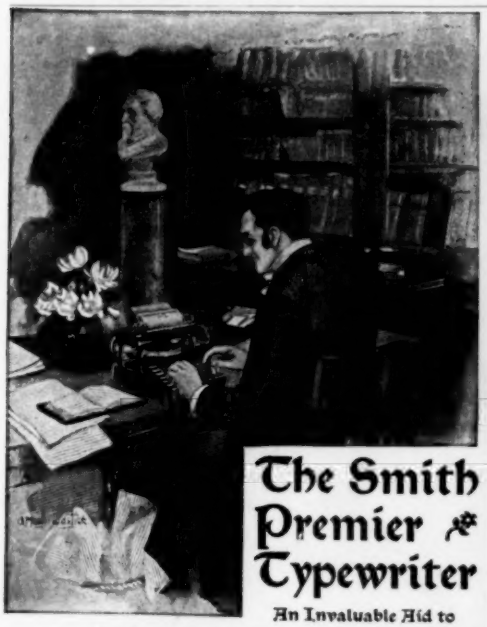

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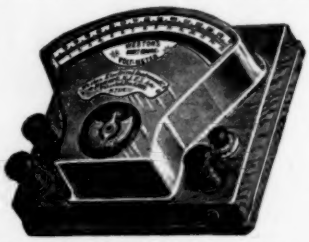

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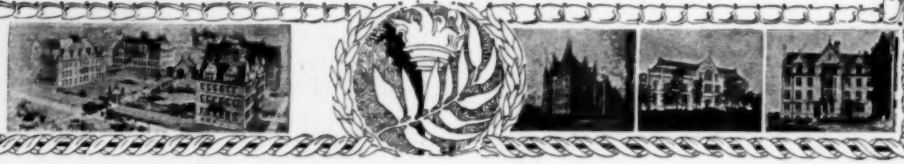

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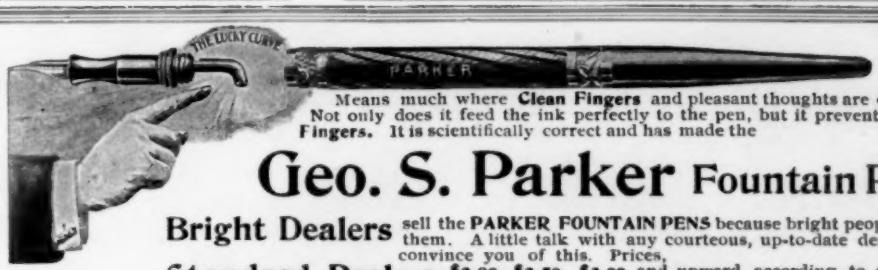

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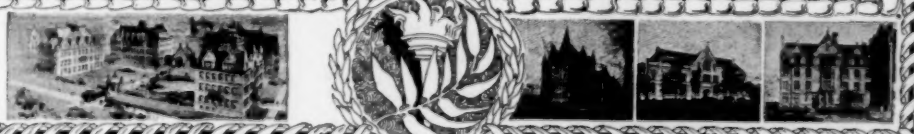

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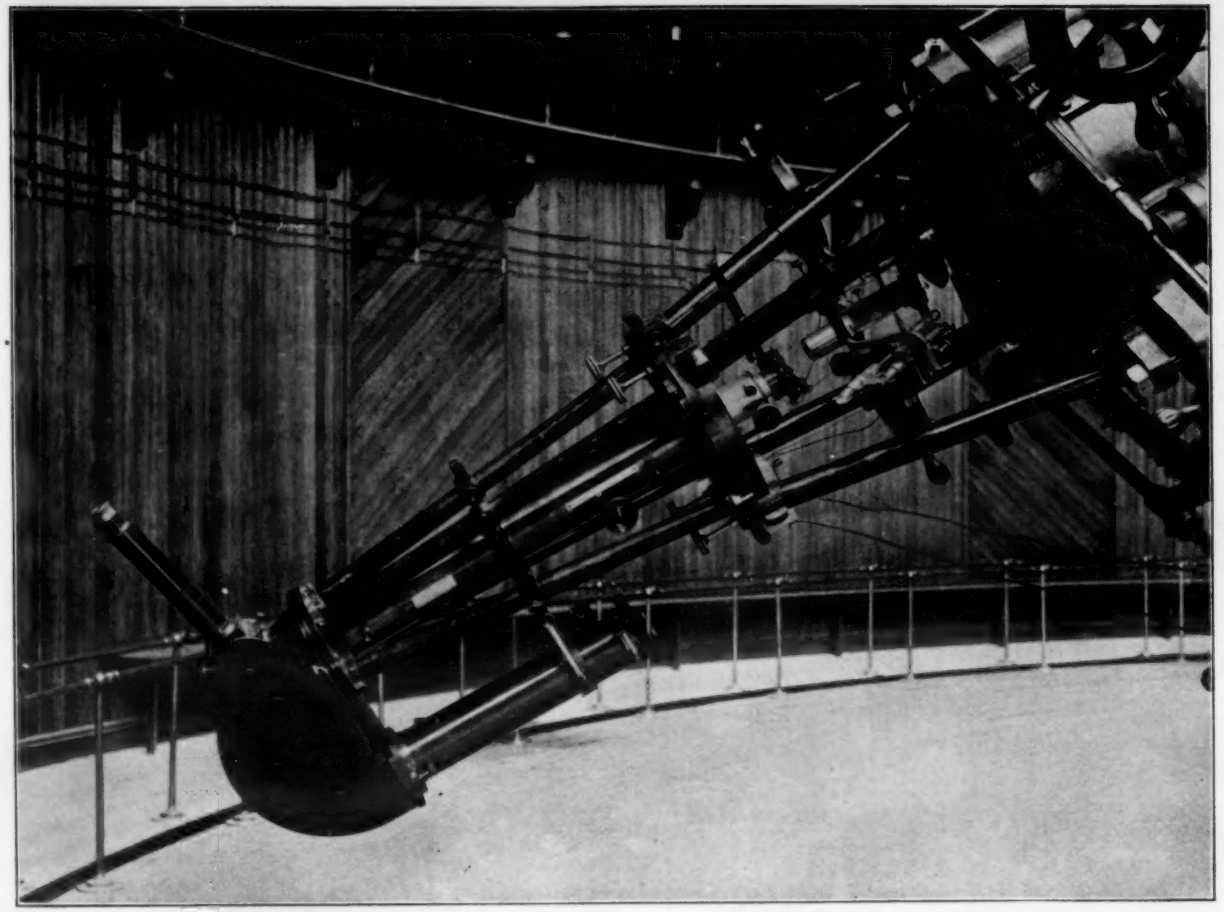

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